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FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 63-12

SMALL ROCKET LIFT DEVICE
PHASE III
TESTING OF THE ASSEMBLED SYSTEM

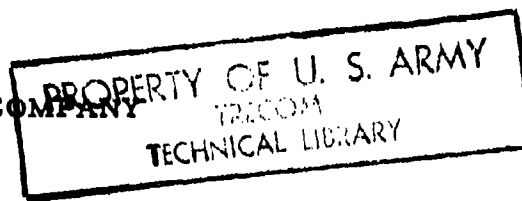
Task 1D121401A14175
(Formerly Task 9R38-01-017-75)

Contract DA 44-177-TC-642

April 1963

prepared by:

BELL AEROSYSTEMS COMPANY
Buffalo, New York



22 JUL 1963



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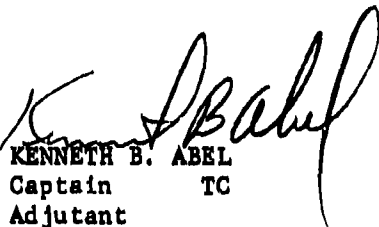
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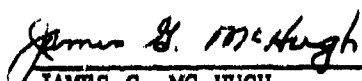
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This report has been reviewed by the U. S. Army Transportation Research Command and is considered to be technically sound. The report is published for the exchange of information and the stimulation of ideas. .

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FOREWORD

For the past 12 months, Phase III of the TRECOM SRLD feasibility program and Bell R&D efforts have been continuing. After the original feasibility model was so successfully demonstrated, additional work and studies were initiated to improve the elements which were only lightly touched upon in the early work.

The US Army Transportation Research Command has assigned Mr. Robert Graham as project officer; his understanding help and advice have been of great value during these efforts. Mr. Wendell Moore served as Technical Director on the program for Bell Aerosystems Company.

Phase III of the SRLD program was initiated on 22 December 1961 and completed 15 December 1962.

CONTENTS

<u>Section</u>	<u>Page</u>
SUMMARY	1
CONCLUSIONS	5
RECOMMENDATIONS	7
I PROPELLANT QUANTITY SENSING AND WARNING SYSTEM	9
II PARAGLIDER LIFT AUGMENTATION STUDIES AND EXPERIMENTS	25
A. General	25
B. Captive Flight Test Program	43
1. Aerodynamic Performance	51
2. Aerodynamics of Launch	59
3. Aerodynamic Stability and Control	63
C. Structures	66
1. Discussion	66
2. Design Criteria	66
3. Analysis	69
III STABILITY AND CONTROL	89
A. Summary	89
B. Introduction	89
C. Method of Analysis	92
D. Displays	95
E. Results	99
F. Conclusions	105
IV HUMAN FACTORS	107
A. General	107
B. Flight Test Background	107
1. General Background	107
2. Trainee Background	110
3. Analysis of Training Performance	143
4. Effect of Inter-Trial Interval on Learning	150
C. Selection and Training Criteria	154
D. Tethered and Free-Flight Training Program	156
E. Training of Maintenance and Servicing Personnel	165

<u>Section</u>		<u>Page</u>
V	INDEPENDENT R&D PROGRAM	169
VI	REFERENCES	171
Appendix I	SUPPLEMENTARY INFORMATION	173
Appendix II	"A" BELT SUPPLEMENTAL TEST DATA	177
Distribution	181

ILLUSTRATIONS

Figure		Page
1	Demonstration Flight Over Tree.	4
2	Capacitive Probe Fuel Indicator and Low-Level Warning System.	11
3	Sight Glass Fuel Indicator and Low-Level Warning System.	12
4	Magnetic Switch Fuel Indicator, Low-Level Warning System and Schematic Diagram	14
5	New Throttle Handle Installation and Float Tube-Magnetic Switch Assembly.	16
6	Mass Excitation Designs	17
7	Vibrating Unit Mounted Atop Pilot's Helmet.	18
8	Vibrating Unit Mounted on Yaw Handle.	20
9	Vibrating Unit Mounted on Rear of Pilot's Helmet	21
10	Knocker Unit Mounted on Pilot's Helmet	22
11	Propellant Quantity Indicator Light Test Data.	24
12	Inflatable Paraglider Model Flying in Hangar.	26
13	Full-Size Mylar Nose Section (3 Beams).	28
14	Full-Size Mylar Nose Section (2 Beams).	29
15	Chloroprene Coated Nylon Model Nose Section.	30
16	Inflated Paraglider Test Structure.	31
17	Failure of Paraglider Test Structure.	32
18	Paraglider General Arrangement.	35
19	Second Paraglider Structure.	37
20	Paraglider Suspension System Mockup.	38
21	Model, Paraglider Suspension and Control System.	39
22	Paraglider Harness and Mast Assembly.	40
23	Paraglider in Captive Flight.	44
24	Paraglider Tow Tests - Manned and Unmanned.	46
25	Preinflated Launch Techniques Over Water.	50
26	Paraglider Performance.	53
27	Manned Paraglider Performance.	54
28	Manned Paraglider Performance - Glide Version.	55
29	Paraglider Flare Trajectories.	57
30	Paraglider Flare Trajectories.	58

ILLUSTRATIONS

Figure		Page
1	Demonstration Flight Over Tree.	4
2	Capacitive Probe Fuel Indicator and Low-Level Warning System.	11
3	Sight Glass Fuel Indicator and Low-Level Warning System.	12
4	Magnetic Switch Fuel Indicator, Low-Level Warning System and Schematic Diagram	14
5	New Throttle Handle Installation and Float Tube-Magnetic Switch Assembly.	16
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8	Vibrating Unit Mounted on Yaw Handle.	20
9	Vibrating Unit Mounted on Rear of Pilot's Helmet	21
10	Knocker Unit Mounted on Pilot's Helmet	22
11	Propellant Quantity Indicator Light Test Data.	24
12	Inflatable Paraglider Model Flying in Hangar.	26
13	Full-Size Mylar Nose Section (3 Beams).	28
14	Full-Size Mylar Nose Section (2 Beams).	29
15	Chloroprene Coated Nylon Model Nose Section.	30
16	Inflated Paraglider Test Structure.	31
17	Failure of Paraglider Test Structure.	32
18	Paraglider General Arrangement.	35
19	Second Paraglider Structure.	37
20	Paraglider Suspension System Mockup.	38
21	Model, Paraglider Suspension and Control System.	39
22	Paraglider Harness and Mast Assembly.	40
23	Paraglider in Captive Flight.	44
24	Paraglider Tow Tests - Manned and Unmanned.	46
25	Preinflated Launch Techniques Over Water.	50
26	Paraglider Performance.	53
27	Manned Paraglider Performance.	54
28	Manned Paraglider Performance - Glide Version.	55
29	Paraglider Flare Trajectories.	57
30	Paraglider Flare Trajectories.	58

ILLUSTRATIONS (CONT)

Figure		Page
31	Towing Velocity versus Towing Angle for Stable Flight.	60
32	Towing Velocity versus Tow Line Attachments Point for Stable Flight.	61
33	Towing Velocity versus Tow Line Tension for Stable Flight.	62
34	Center-of-Gravity Position for Varying Stability and Trim.	64
35	Static Stability.	65
36	Mylar Allowable Bending Moment and Pressurization	73
37	Bending Moment Allowable Tapered Leading Edge Tube.	74
38	Structural Tube Selection	75
39	Structural Limit and Deflection Curves	78
40	Load Versus Deflection Curves.	86
41	Structural Limit and Deflection Curves.	87
42	SRLD with Mounted Instrumentation.	90
43	Telemetry Equipment Installed in Trailer.	91
44	Block Diagram of Man-Machine Combination.	92
45	Mathematical Model of Two-Segment Body	94
46	Oscilloscope Yaw-Altitude Display.	95
47	Simulated Analog Control Rig Mockup	97
48	Oscilloscope and X-Y Plotter Display for Longitudinal and Yaw Flights.	96
49	Improved REAC Simulator Display	98
50	X-Y Plotter Display for Forward Flight.	100
51	Yaw Control Sensitivities Used in Analog Simulation.	101
52	Test Results of Hovering Turn Studies	103
53	Trainee Performing Tethered Flight.	108
54	Operation Maximum Pulse Rate versus Number of Flights.	144
55	Skill Acquisition as a Function of Total Thrust Duration.	146
56	Skill Acquisition as a Function of Number of Attempts on Throttle per Flight	147

ILLUSTRATIONS (CONT)

Figure		Page
57	Skill Acquisition as a Function of the Average Duration of Attempts per Flight	148
58	Trainee Proficiency versus Experience	149
59	Comparison of Performance on the First and Second Attempts.	151
60	"A" Belt Propellant System (90% H ₂ O ₂) Compatibility as a Function of Tank Loadings and Total Days Since Last Conditioning Process	179

TABLES

1	Tensile Test	77
2	Tensile Test	83
3	Joint Tensile Test	84
4	Internal Pressurization Cycle Test	85
5	Comparisons Between Mean Improvement Realized After Long Inter-Trial Intervals (Distributed Practice) with Mean Improvement Realized After Short Inter-Trial Intervals.	152
6	Anthropometric Data.	157
7	Frequency of Problems Encountered in SRLD Developmental Flights for Each Control Component . .	161
8	Rank Order of Difficulty of Control Component in Developmental Tests Compared with Order of Introduction of Component in Training Series	162
9	Flight Plan for Tethered Sequence Control Task	164
10	Free-Flight Plan	166
11	Calculated Performance of Various SRLD Configurations Utilizing H ₂ O ₂ as Propellants	169

SYMBOLS

N_Z	=	Load factor (acceleration) in z direction
N_X	=	Load factor (acceleration) in x direction
α	=	Angle of attack (degrees)
L.E.	=	Leading edge
T.E.	=	Trailing edge
C	=	Chord length (inches)
W	=	Loading (lb/in.)
R_1, R_2	=	Load reactions (pounds)
M	=	Bending moment (in.-lb)
q	=	Loading (lb/in.) (Section II)
P_c	=	Axial compressive force (pounds)
θ	=	Angle (radians) (Section II)
x,y	=	Coordinate system ordinates (inches)
R	=	Radius (inches)
σ_H	=	Membrane stress in hoop direction (psi)
σ_M	=	Membrane stress due to bending moment (psi)
f_c	=	Compressive stress (psi)
I	=	Moment of inertia of cross section
F_{ty}	=	Material yield tensile allowable (psi)

SYMBOLS (CONT)

F_{co} = Allowable compressive stress (psi)

t = Thickness (inches)

D = Diameter (inches)

X_o, Y_o, Z_o = Earth coordinates of hip joint (feet)

m_1 = Mass of upper body (slugs)

m_2 = Mass of lower body (slugs)

T = Thrust (pounds)

z_1 = Distance from upper body center of gravity to hip joint (feet)

z_2 = Distance from lower body center of gravity to hip joint (feet)

p = Roll rate (rad/sec)

q = Pitch rate (rad/sec) (Section III)

r = Yaw rate (rad/sec)

θ = Pitch attitude (rads) (Section III)

ϕ = Roll attitude (rads)

ψ = Yaw heading (rads)

g = Acceleration of gravity (32.2 ft/sec²)

K_θ = Pitch hip spring constant (ft-lb/rad)

K_ϕ = Roll hip spring constant (ft-lb/rad)

k_y = Radius of gyration about y body axis (feet)

SYMBOLS (CONT)

- θ_c = Control angle deflection (rads)
- Δz = Distance from upper body center of gravity to control point (feet)
- $\delta \eta$ = Nozzle deflection (rads)
- N = Yawing moment (ft-lb)
- l = distance from nozzle center line to center of gravity (feet)
- A dot over a symbol indicates differentiation with respect to time.

Subscripts

- | | |
|-----|----------------------|
| 1 | Refers to upper body |
| 2 | Refers to lower body |
| tot | total |

SUMMARY

Several years ago, in answer to a generalized Army desire for increased mobility of the foot soldier, an approach was conceived wherein small rocket units are attached directly to an individual to provide him with short controlled flight capability.

As a result of this desire, the U. S. Army Transportation Research Command (TRECOT) awarded Aerojet General Corporation a study contract to investigate the theoretical feasibility of such devices. Following this, a contract was awarded the Bell Aerosystems Company to substantiate the theoretical investigations with fabrication and testing of actual free-flight hardware. This task was performed in two phases. Phase I required the fabrication of components as well as testing and assembly of the Small Rocket Lift Device (SRLD) followed by an engineering report. Phase II required static test firings of the assembled unit, and manned tethered and free-flight testing to determine the overall feasibility, performance, and safety of such a device. This Phase II program was highly successful and was concluded with a free-flight demonstration to Government representatives at the end of 28 free flights. The results of the Phase II work are contained in TRECOT Technical Report 61-123, November 6, 1961.

Phase III of this effort consisted of four fundamental tasks:

1. The development of a suitable propellant quantity warning and indicating system.
2. The design and test of a paraglider lift augmentation device for use with the SRLD.
3. Performance of stability and control studies utilizing data in possession of the Contractor from an instrumented rocket belt flight test program to be conducted by the US Air Force.
4. Performance of a human factors study for the purpose of determining optimum trainee selection criteria and establishing SRLD training requirements.

In addition, Bell Aerosystems agreed to furnish data from their independent R&D configuration studies in this Phase III report.

A satisfactory propellant quantity indicating system was designed and tested which could be utilized in either pressurized versions of the SRLD or unpressurized versions. After experimenting with many types of physical warning devices, we reverted to the original type of bone conduction warning system used originally on the feasibility model.

Several paraglider designs were studied. One was approved for fabrication and test by the Contracting Officer and two inflatable models were built and tested. A preinflated tow launch flight test program was carried out. Several manned towed flights were achieved to altitudes of approximately 40 feet and distances of approximately 200 feet. After experiencing considerable difficulty in maintaining a leakproof pressurized structure and encountering problems with packaging, inflation, and deployment, several magnitudes greater than anticipated, the program was terminated (after discussions with TRECOM).

Stability and control portions of this Phase III program were not completed due to the lack of data which were supposed to have been obtained from an instrumented flight test program supported by the U.S. Air Force under contract number AF18-600-1923. This program was terminated by the Air Force after damage to several of the accelerometers on one of the test flights and extensive difficulties arising in the development of a suitable telemetering data acquisition system. Preliminary work, however, resulted in development of the REAC simulator to the point where it would realistically respond and record flight paths as a result of pilot control inputs.

A considerable amount of human factors data was accumulated due to the fact that we trained two pilots, one on this Phase III program and one on Bell R&D efforts. As a result, we were able to establish preliminary criteria for pilot selection as well as establish a reasonably good training program.

Numerous configurations were studied on the Bell R&D program ranging from cleaned-up pressurized versions of the feasibility model through unpressurized expander turbine driven fan versions. In addition, numerous improvements were made as a result of flight test work on the "B" belt which was built and flown during this period. Several milestones were achieved in rechecking the performance and compatibility of the "A" belt. These data are shown in Appendix II. Forty seven flights were made

on the Army "A" belt during Phase III for contractual purposes. Twelve "A" belt demonstration flights were made at various places throughout the country. One hundred and fifty-two flights were made on the Bell "B" belt, of which 17 were demonstration flights. As a result of extensive flight testing and flight technique development on the "B" belt, we have increased the range from 368 feet to a demonstrated 815 feet with 10 pounds of propellant remaining. We increased the demonstrated flight speed from 35 miles per hour to something over 60 miles per hour. We increased the maximum demonstrated flight altitude from approximately 30 feet to well over 60 feet. One such flight is depicted in Figure 1, which shows an SRLD pilot topping a tree.



Figure 1. Demonstration Flight Over Tree

CONCLUSIONS

The magnetic float propellant quantity indicating and warning system which was designed and tested has worked satisfactorily. The physical warning portion of this system, however, needs improvement. In-flight visual indication has proven unsatisfactory. The installation of the bone conduction warning buzzer inside the back of the helmet, instead of on the back of the operator's throttle hand, remains the most detectable warning method. However, it still seems desirable to devise a warning system which can be attached permanently to the belt instead of having to attach the system to the pilot's helmet.

Studies of the paraglider indicate that the concept was entirely feasible and could become a usable auxiliary lift device. The limited tests performed on a preinflated full scale paraglider served only to identify the system problems and their magnitude. Achieving a reliable leak-proof structure, small package size, satisfactory deployment, and inflation were probably the greatest of the many problems encountered.

Analog simulation incorporating six-degree-of-freedom dynamics permitted satisfactory simulated translatory flights and yaw control power studies. The yaw control power study indicated that a considerable amount of yaw control power variation could be tolerated by SRLD pilots. It also indicated that there is a tendency for the pilot to operate the yaw control along with throttle motion. Difficulty in developing a workable telemetry and instrumentation system prevented acquisition of flight test data for correlation with analog studies.

As a result of these mechanized computer studies, a secondary but important gain was made by utilization of the simulator for training. The net result should be quicker, less costly pilot training in the future.

Great strides were made during the course of this task toward a satisfactory simulator; however, the display status leaves much to be desired and is primarily responsible for the existing limitations in this simulation.

Satisfactory preliminary pilot selection criteria were established. These criteria indicate that the ideal trainee would possess the following characteristics:

Age	18 to 25 years
Height	Approximately 5 feet 10 inches
Weight	150 to 165 pounds
Body Build	Slender to medium
Experience	Background in aviation or some experience in stressful situations
Temperament	Cool, calm, nonanxious
Education	High School graduate to one year of college
Motivation	Volunteer with high desire to fly the belt
Motor Skills	A well developed set of motor skills; well coordinated
Physical Qualifications	An individual capable of passing the Army induction physical was deemed acceptable.

The SRLD training program was substantially improved during this period. A forty flight program consisting of 25 tethered and 15 free - flights appears to be sufficient at this time.

Independent configuration and performance improvement studies indicate that the next major step in design and testing of the SRLD should be completion of a nonpressurized, pump-fed, peroxide version which can be used either with nozzles or with lift fan devices, interchangeably. Considerable theoretical and experimental work must still be done to obtain a satisfactory tactical propellant propulsion system. Numerous improvements on the B belt have led to great demonstrated performance improvements and to much better controllability.

Limited flight testing of a single-arm controller, which incorporated mechanically coordinated yaw and lateral controls, indicated that it could be made to work satisfactorily. Learning to fly this configuration on a straight line tether is difficult. Psychologically, the pilots preferred having two arm extensions since it seems to represent some form of in-flight security.

RECOMMENDATIONS

As a result of the phase III work on the SRLD contract and Bell independent R&D efforts, the following recommendations are made:

1. Perform additional flight testing with simplified instrumentation to gain quantitative stability and control data for prototype specification.
2. Continue design studies and experiments with auxiliary lift devices in an effort to obtain a small, lightweight range augmentation and emergency let-down device.
3. Design, construct, and test an unpressurized pump-fed version of the SRLD which can utilize either nozzles or small fans as lift devices.
4. Perform a preliminary design and construct a prototype jet engine for use as the primary propulsion system for long-range flying belts.
5. Perform additional design studies and experimental flight tests to reduce the noise level of the SRLD in flight.
6. Continue the development of the single hand control system.
7. Perform a rigorous operational test program with several SRLD's to determine their usefulness for tactical situations.
8. Continue fundamental configuration studies to constantly improve the rocket belts in performance, controllability, range, and weight.

I. PROPELLANT QUANTITY SENSING AND WARNING SYSTEM

As a result of the initial flight development program on the feasibility model, it was deemed desirable to develop a direct-sensing propellant-quantity level and physical warning system for advanced models of the SRLD. Toward this end, we were assigned a task on this modification of the contract to develop such a system which not only could be utilized on the pressurized feasibility version, which exists today, but also could be used on possible future models.

The task involved studying various methods which could possibly be used and selecting at least one for detail design and approval for fabrication by the Contracting Officer, after which we were to fabricate and flight test the system on the feasibility SRLD model.

Our efforts resulted in the study of four different methods of indication of propellant quantity and physical warning stimuli. Each method activates a warning signal when fuel level drops to a predesignated low level. Warning in all four cases can be given by the same type of device, i.e., a small indicator lamp for visual alarm and an electromechanical vibration for physical stimulus. The latter is developed by a miniature, permanent magnet, direct-current motor driving an unbalanced flywheel. Motor and flywheel are enclosed to prevent any mechanical interference with free rotation. The unit is placed in contact with a sufficiently sensitive part of the pilot's body so that he will unmistakably feel the vibration. This could be inside the crash helmet against the rear of the head, or on an elastic band worn about the wrist, forearm, calf, etc.

In the first method, a capacitive probe is used. A high-frequency ac voltage developed by an oscillator is applied to a bridge circuit composed of two resistive and two capacitive legs. One capacitive leg is formed by the fuel tank probe and a shunt capacitor; the other, by a combination of fixed and variable capacitance for balance adjustment. The bridge is balanced with a full tank. As fuel is used, the bridge output increases. This signal is amplified, rectified and applied to a calibrated microammeter for continuous indication of fuel level. The rectified signal is also coupled through a Zener diode to a control amplifier and blocking oscillator which, when a preselected low fuel level is reached, pulses the warning circuit, beginning at approximately once per second and increasing in frequency until approximately only 5 percent of fuel remains, at which

time warning becomes continuous. This system is completely transistorized and, in its final configuration employing modular construction, including all batteries, will be entirely housed inside the throttle control handle. The only external connections required are the fuel tank probe lead and the lead to the physical stimulus warning vibrator. Figure 2 is a schematic of this system design.

A second method for measurement of hydrogen peroxide fuel and low-level warning utilizes a sight glass and an electrical sensing device attached to the glass for warning actuation. Sight glass tubing capable of withstanding the pressures involved is commercially available.

When coupled to the tank through fittings of compatible materials, fuel level can be observed. Unfortunately, hydrogen peroxide is a colorless liquid and, being a potent bleach, cannot be dyed. Any attempt to add coloring would contaminate the fuel, resulting in dangerous decomposition.

Readability of the sight glass can be improved, however, by mounting a scale with a thin colored stripe immediately behind the glass. The magnifying action of the fluid will assist in discerning the level. As a further means of improving readability, but primarily for the purpose of actuating a warning signal, a hollow capsule of teflon is floated within the sight glass.

A sensing device composed of a miniature light source and a cadmium sulphide photocell, contained in a compact housing, is positioned on the sight glass at a level at which warning is desired. When the fuel level drops to the selected critical level, the opaque float will interrupt the light beam, thereby darkening the photocell. The resulting small current change through the photocell is amplified by a transistor amplifier to actuate a relay, which in turn sets off the warning.

Another similar sensing device, positioned as desired on the sight glass, could be added and connected so that, as the first selected level is reached, a short warning would be given. When the second level is reached, a continuous warning results (see Figure 3).

The third method, a proposal submitted by an outside vendor, was studied. It uses semiconductors in a tank probe assembly arranged to sense the change in thermal conductivity as the fluid level drops below

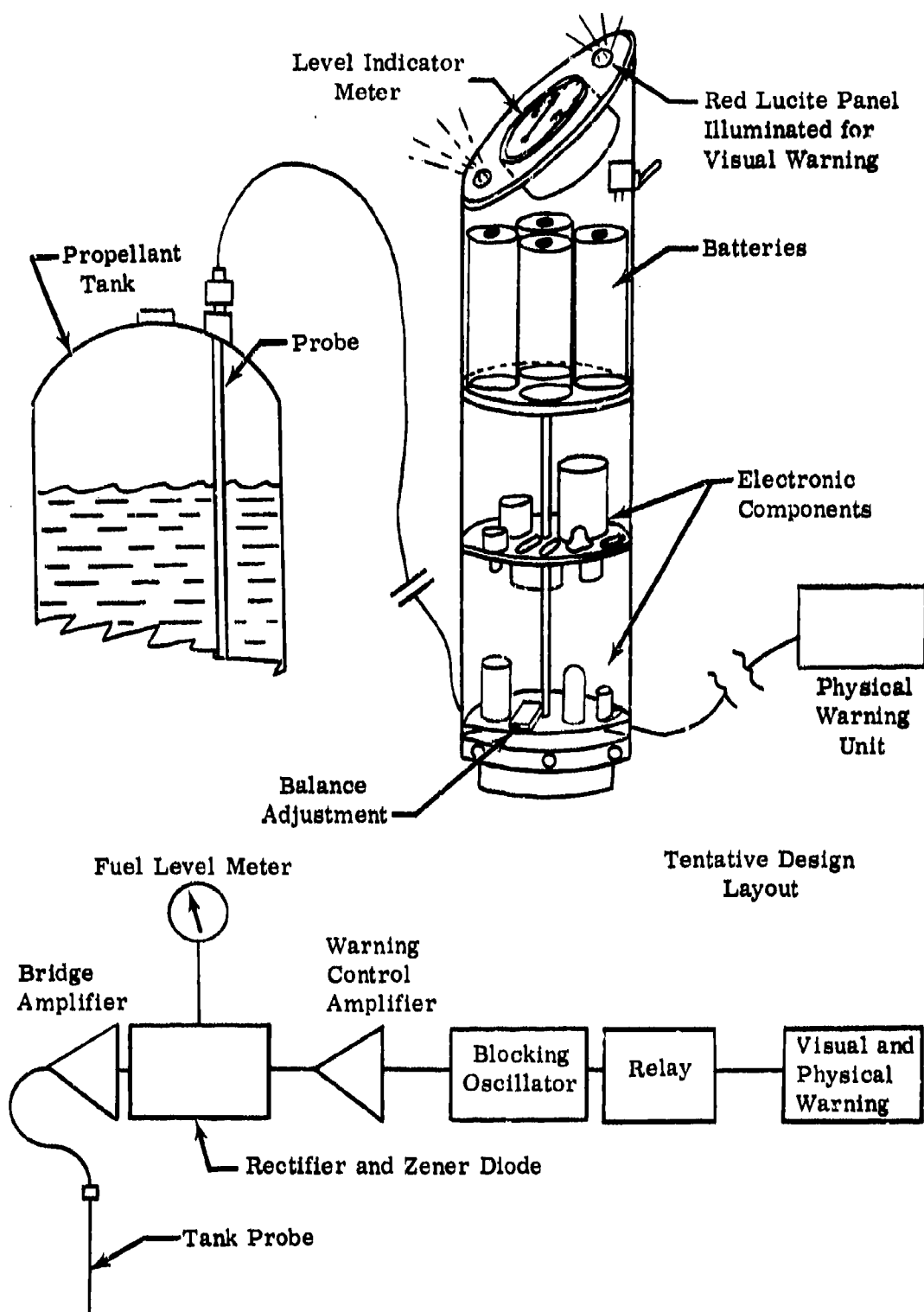


Figure 2. Capacitive Probe Fuel Indicator and Low Level Warning System

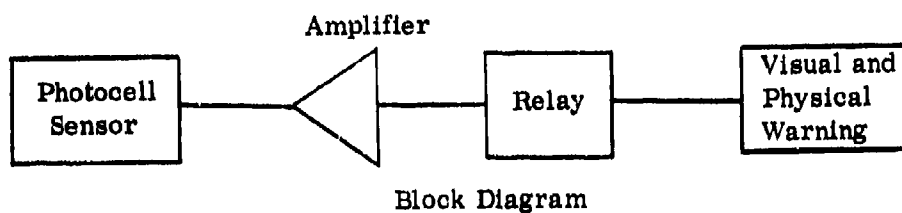
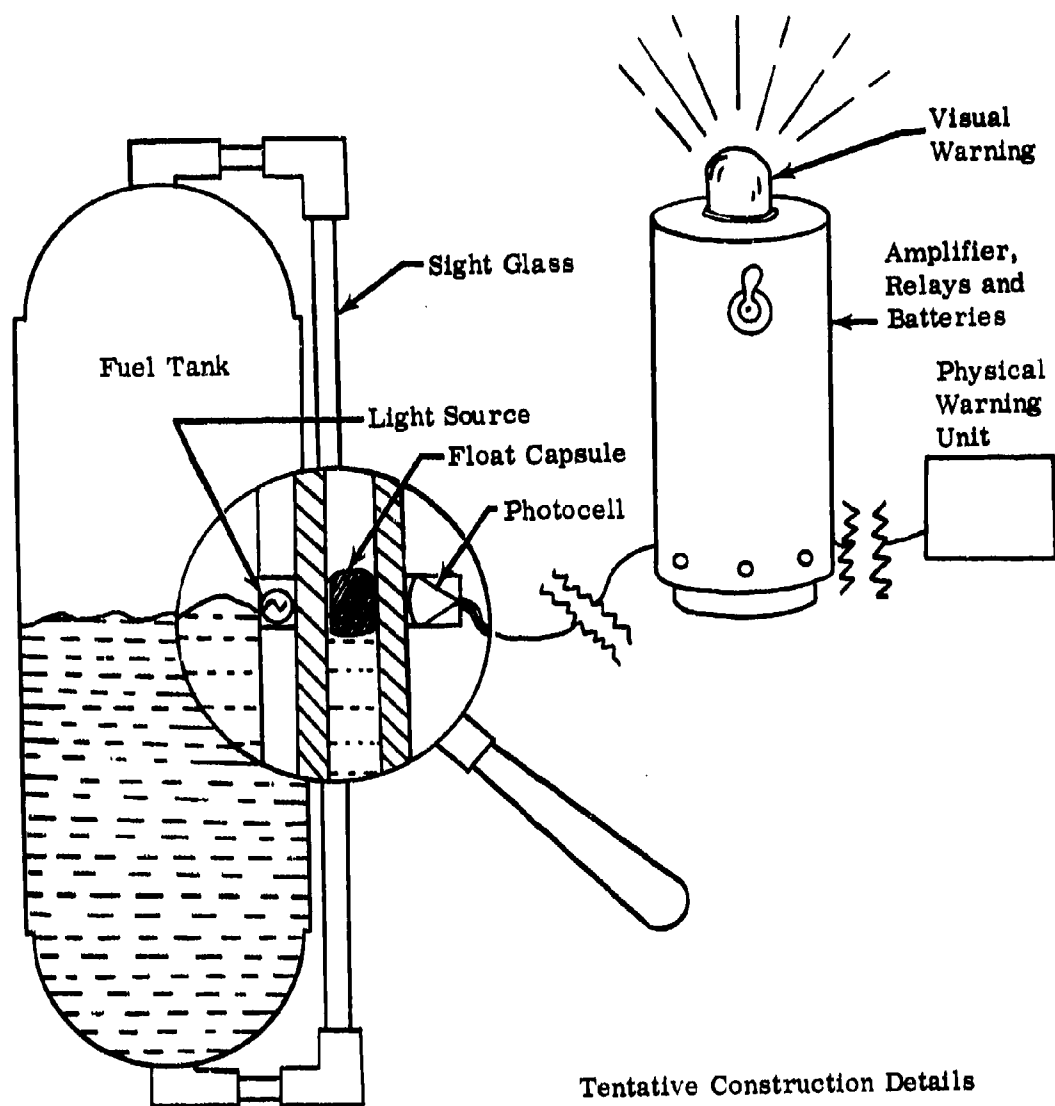


Figure 3. Sight Glass Fuel Indicator and Low Level Warning System

the sensing semiconductor with reference to a similar semiconductor mounted in air at the upper interior of the tank.

A spring loaded selector switch rests at the low-level alarm position. When this low level is reached, the alarm circuit will be energized. Intermediate fuel levels may be determined by rotating the selector switch and noting at which position the alarm is actuated.

A fourth and final system design was studied, based on the use of a magnetized float and magnetically actuated switches. This system was the simplest and lightest one devised. It was subsequently approved by the Contracting Officer for fabrication and test.

In operation, a small magnet, encapsulated in a float, is installed in a vertical stainless tube attached to the outside of the propellant tank and connected to the top and bottom, much the same as a sight glass. When the propellant level drops, the float passes tiny magnetic switches attached to the outside of the tube at appropriate levels, actuating each in turn. Actuation of the switches provides both visual quantity level and physical warning stimulus to the operator. A schematic drawing of the system is shown in Figure 4.

The actual magnet is encapsulated in a welded stainless-steel float capable of withstanding the required tank pressure. The bare magnet itself has been tested in a beaker of 90 percent H_2O_2 . Little reaction of significance occurred. The reaction that occurred resulted in minute bubbles forming and slowly rising to the surface, much the same as a reaction from a poorly cleaned system part.

The magnetic switches are encapsulated in glass and are capable of handling 0.5 amp without the use of a relay. They have been tested for millions of cycles and found to be highly reliable. They are commercially available in quantity at a very nominal price. The size is 1/8 inch diameter and 3/4 inch long.

The miniature lamps utilized are popularly known as "grain of wheat" lamps. They have a life in the order of 1000 hours, and are readily available in electrical supply stores and local hobby shops. These lamps are installed in small holes bored into the colored plastic visual indicating panels mounted at the top of the throttle handle.

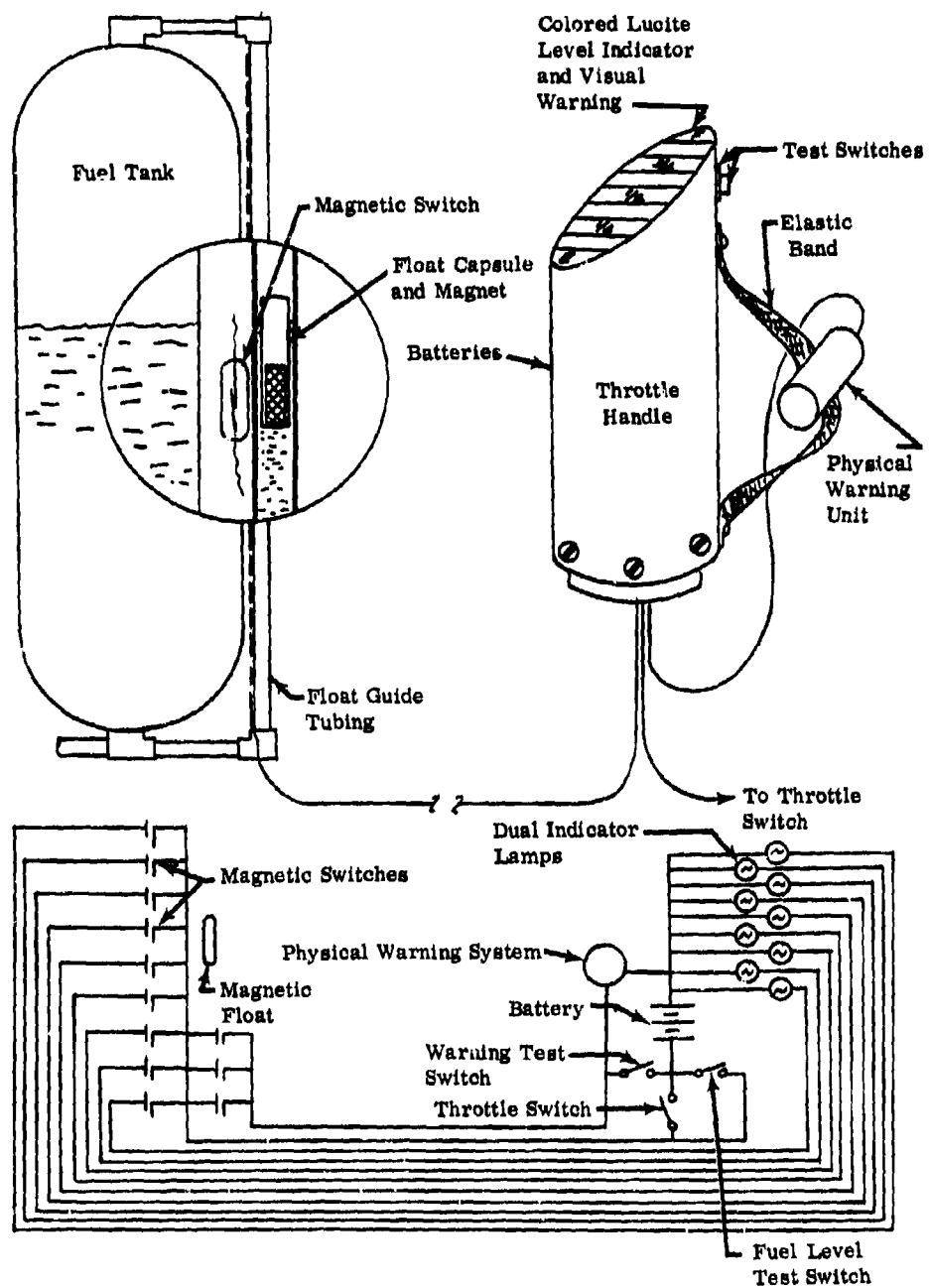


Figure 4. Magnetic Switch Fuel Indicator, Low Level Warning System and Schematic Diagram

As a result of our experimental fabrication efforts, we successfully designed and bench-tested a magnetic float suitable for use in hydrogen peroxide under the pressures involved and bench-tested the subassembly in its tube.

The first of five physical warning stimuli designed and tested consisted of a vibrator motor attached by means of an elastic web to the throttle handle in such a manner that, when the throttle was grasped, the vibrating motor was held firmly against the back of the throttle hand. Figure 5 shows the magnetic float tube subassembly with the magnetic switches attached prior to potting, as well as the assembled throttle handle showing both the lighted quantity indicating panel and the aforementioned hand vibrating unit. The vibrating motor consisted of a miniature permanent ceramic magnet motor equipped with a small off-center flywheel to generate the vibratory signal. It was a commercially available unit. The motor operated on 3 vdc. Flight test of this unit indicated that it was entirely unsatisfactory.

Further study, in conjunction with our vibration experts, indicated that a vertically vibrating yaw handle might well be a good answer to this warning problem. As a result, we designed and bench-tested mockups of two simulated yaw handles with inner masses, spring suspended, and excited by this small 3-volt motor with eccentrics on each end of the armature shaft. These two units designed and bench-tested are shown in Figure 6. Bench tests, however, indicated that these two units also would be unsatisfactory for actual flight use.

Further experiments indicated that possibly tapping on the pilot's helmet would amplify the signal, much as a sound box. We, therefore, embarked on the next experiment, which involved mounting a vibrating relay on the top of the pilot's helmet. This was tried in flight and was also found to be unsatisfactory. The picture of this installation is shown in Figure 7.

The next test, resulting from discussions and experience, indicated possibly the need for more power input in order to increase the intensity of the signal. We therefore changed the electrical circuitry to add a 21-volt mercury battery and relay, which would permit the installation of a 24-volt vibratory motor, the same as used originally on the SRLD. This unit was mounted on the yaw handle with a heavy elastic band, which pressed it firmly against the back of the hand during flight. Flight tests of this unit



Figure 5. New Throttle Handle Installation and Float Tube-Magnetic Switch Assembly

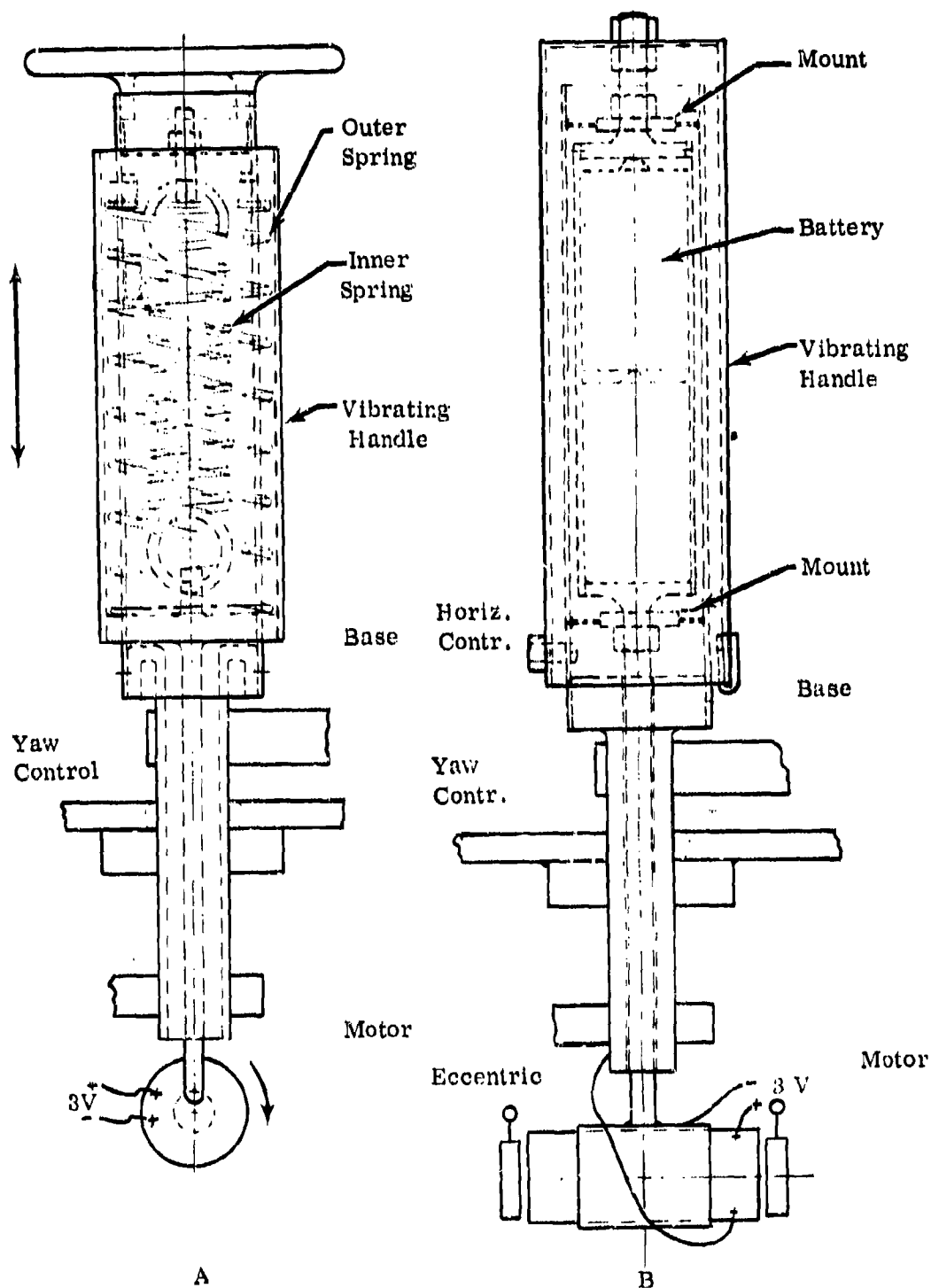


Figure 6. Mass Excitation Designs



Figure 7. Vibrating Unit Mounted Atop Pilot's Helmet

also indicated that it was not satisfactory for free-flight use. Figure 8 is a photograph of this unit as tested.

In the sixth experiment, we placed the same unit in the back of the pilot's helmet much the same as it was originally done on the A belt. Flight test of this unit indicated that it would be very satisfactory for free-flight use. Figure 9 is a photograph of this unit as tested.

The seventh and final attempt to achieve a system which could be clipped on to the pilot's helmet, but wired to the belt itself, was tried, utilizing a doorbell knocker actuated by the magnetic-float warning system. The knocker was placed in a position as close as practical to the pilot's mastoid bone adjacent to the right ear. This unit was fabricated and tested in flight. It, however, did not prove satisfactory. Figure 10 is a photo of this knocker installation installed on the pilot's helmet.

As a result of all our experiments with warning devices, we are forced to conclude that the best type of warning device developed to date is the 24-volt bone conduction vibratory unit mounted in the back of the head as originally used on the feasibility model as shown generally in Figure 9.

The propellant quantity indicating system of lights on top of the throttle handle worked out very successfully. They were utilized for a total of 11 tethered flights. On the first three flights, the magnetic switches and wiring were merely taped in place around the tube and held with an external rubber hose surrounding the tube assembly. On two of these first three flights, we found malfunctions of the lights. The malfunctions were subsequently traced to loose connections, due to shifting of the magnetic switches during the handling of the belt. The entire assembly was rechecked and potted, beginning with the fourth flight. From that time on, it worked perfectly on all flights. The position of the lights was noted during several of our test flights between each of three or four short hops in order to obtain a running check on the light positions. These test data are indicated in Figure 11. A close inspection of these data may possibly indicate to the casual observer that these are not completely consistent. However, it must be realized that these light positions versus time are a function of the type of flight, or short hop, that was being made at the time. For example, if the pilot was translating with full throttle, he would use more



Figure 8. Vibrating Unit Mounted On Yaw Handle

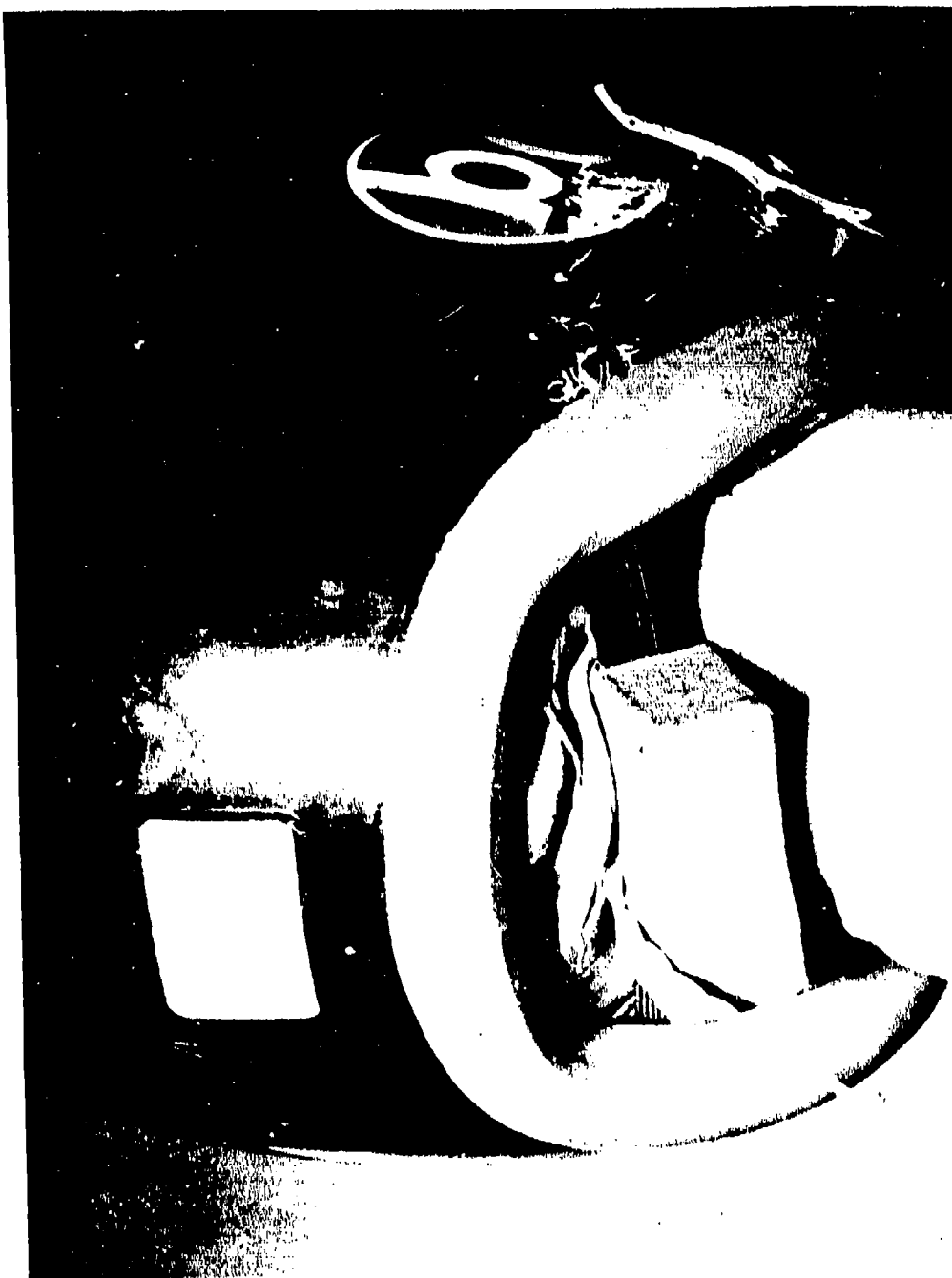


Figure 9. Vibrating Unit Mounted on Rear of Pilot's Helmet



Figure 10. Knocker Unit Mounted on Pilot's Helmet

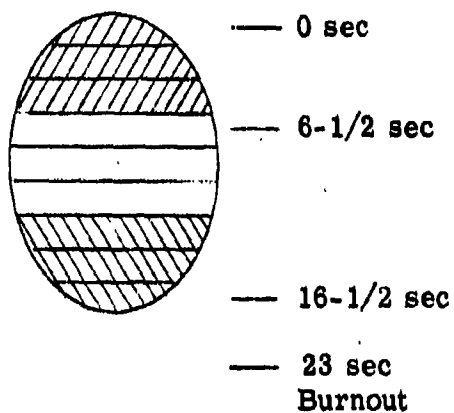
propellant in a given time to remain airborne than if he were hovering. Therefore, these data must be construed only as a general indication that the float, generally speaking, was operating in the position in which it should be at the approximate flight time which existed. Bench tests of this system indicated, however, that it was accurate within \pm two pounds of propellant remaining or approximately \pm one second flight time.

A push-to-test button was installed on the throttle handle and was found to work satisfactorily on all occasions; however, this merely tests the proper functioning of the warning lights. A convenient method however, of checking the actual float operation prior to flight was found when our technicians utilized the system in reverse during filling. On two occasions, they actuated the power to the system during the filling operation and the lights were observed to proceed from the empty to the full in a reverse order. In addition to the foregoing checks, a small magnet was provided on the A belt for manually stroking it up and down the outside of the float-tube magnetic-switch assembly to check each individual magnetic switch if desired prior to flight.

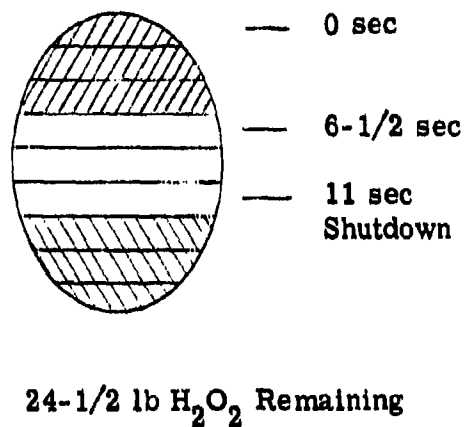
In summary, it is felt that we have developed a satisfactory propellant indicating device as a result of our efforts, and that we have a warning device which is satisfactory for free-flight use. Pilot opinion of the operation of the quantity system indicates that the system will become more and more useful and valuable as flight time of the rocket belts is extended beyond what it is today. In the majority of our free flights, however, we make one long flight which utilizes a great majority of the propellant and do not utilize the remaining for a second flight.

It is concluded that, although we have developed what we feel to be a workable quantity-indicating and physical warning system, further work is required to simplify it and, if possible, to devise a warning system which can be attached permanently to the belt instead of having to attach the system to the pilot's helmet or some portion of his anatomy.

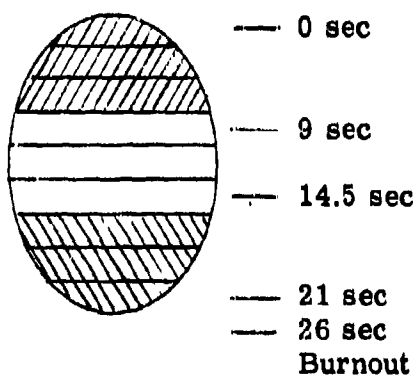
8-30-62 Flight No. 1



8-30-62 Flight No. 2



9-12-62 Flight No. 4



9-14-62 Flight No. 5

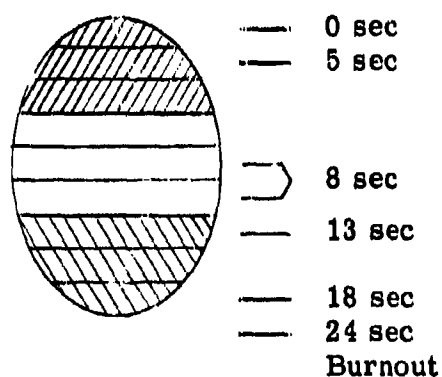


Figure 11. Propellant Quantity-Indicator-Light Test Data

II. PARAGLIDER LIFT AUGMENTATION STUDIES AND EXPERIMENTS

A. GENERAL

The studies of the SRLD operating characteristics indicated the desirability for both a range increasing device such as a wing or other inflatable type structure, and a device which would permit lowering the operator when he may possibly run out of propellant in the process of stretching the range of the SRLD to the utmost. The number of possible configurations are, of course, practically unlimited; however, due to the problems which would undoubtedly be associated with the physical handling characteristics of a rigid rotor or wing large enough to be useful, it was decided that a prepackaged inflatable lifting device would be the most practical approach.

Concurrently, NASA had been experimenting with a device called a paraglider at Langley. This was an inflatable structure with a flexible cloth wing which apparently had good handling and control characteristics as well as an L/D performance suitable for what we might need in conjunction with the SRLD. Toward this end, Bell was assigned the task on this modification of the feasibility contract to perform design studies on various paraglider configurations. After the recommended configuration was established, an informal report with drawings was submitted to the Contracting Officer for approval. Following approval, we were to fabricate two such devices and, if tests proved them feasible, they were to be flown in conjunction with the SRLD.

Work was begun on the paraglider program by fabricating a 5-foot inflatable all-polyethylene paraglider and suspending a small doll beneath it. This was preinflated and hoisted to the top of the Bell flight hangar for drop tests; the purpose of this experiment was to determine, in general, the flight characteristics of such a glider. Figure 12 depicts this model paraglider in flight.

Plain Mylar films were first investigated for possible use as the primary inflatable structural material. We investigated various sealing techniques (namely, heat sealable tapes and ultrasonic sealing) and experimented with various joint designs. Several small bags approximately 4 inches in diameter and 10 inches long were fabricated ultrasonically and tested to burst. Several of these bags exhibited burst pressures as high

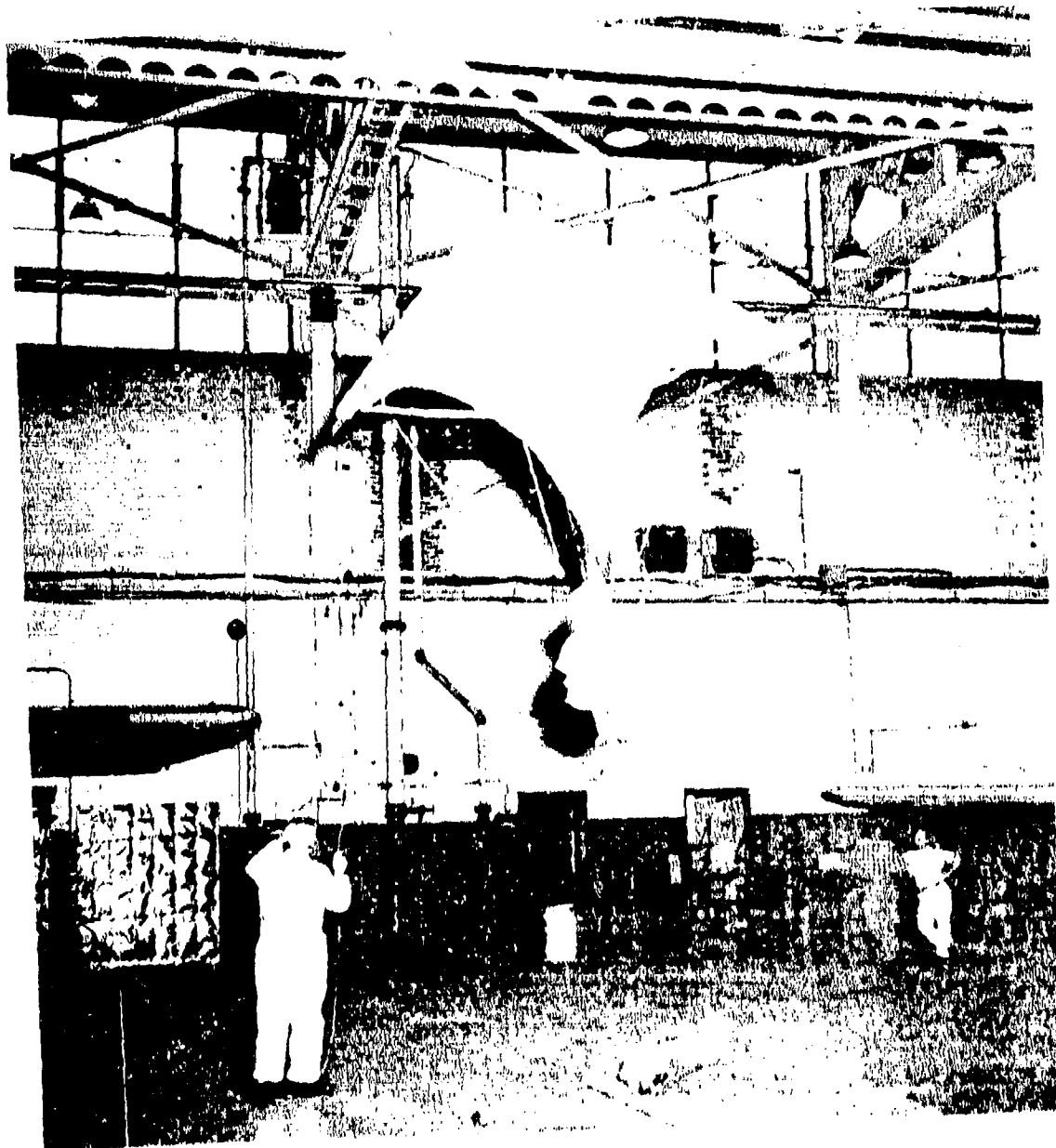


Figure 12. Inflatable Paraglider Model Flying in Hangar

as 16 psi. It was learned during these experiments that ultrasonic sealing does an apparently fine seaming job; however, it seriously weakens the joint in so doing. The best joints were fabricated from heat-sealed tape. We designed and fabricated several full-size nose sections of the paraglider from one mil Mylar films. Two such inflated Mylar structures are shown in Figures 13 and 14. In several variations of these nose joint assemblies, we tried internal tension members to aid in holding the true nose shape. These did not work too well. During the course of these experiments, we found that when Mylar was folded several times and wrinkled, it began to develop numerous pinholes which caused the structure to lose its pressure. At this point, we abandoned Mylar film as a sole structural material.

Following this and after discussions with Irving Air Chute people, we tried chloroprene-coated nylon which weighed 7.37 ounces per square yard. This material is used by Irving as an antigravity suit bladder material. We successfully fabricated a 3-foot nose section from this material and subsequently pressurized it numerous times to 10 psi without problems. This original model is shown in Figure 15. It can be seen from the photograph, however, that additional work needed to be done to overcome the problem of built-in wrinkles and learning to orient the fabric to derive the true desired shape. The model shown was made from plain, flat, patterned material and sealed in the inside edges using a bias tape with special adhesive. This tape takes the tension load across the joint rather than allowing the joint to be loaded in "tear". We purchased a small quantity of 4.4-ounce neoprene coated material with which we made a full-size structure for fabrication technique and structural testing investigations. Figure 16 is a photo of this test structure. It should be noted that the beams were 1 to 2 feet longer than the final length. During the first inflation test, one of the webs in the nose section failed in tension. We subsequently opened the nose section and added two additional tension webs and strengthened the original two. The structure was then reassembled and pressure tested. During the second pressure test, the structure ripped at 2 psi. The failure was determined to be a stress concentration occurring at the end of one of the tension webs in the nose. A photo of this failure is shown in Figure 17. Remedial action taken was the addition of 6-inch round doublers at the ends of each of the tension web joints on the inner surface of the paraglider structure. These formed a stress relief area.

Continuing aerodynamic, structural, control, and configuration design work led to an overall design which was sent to the TRECOM

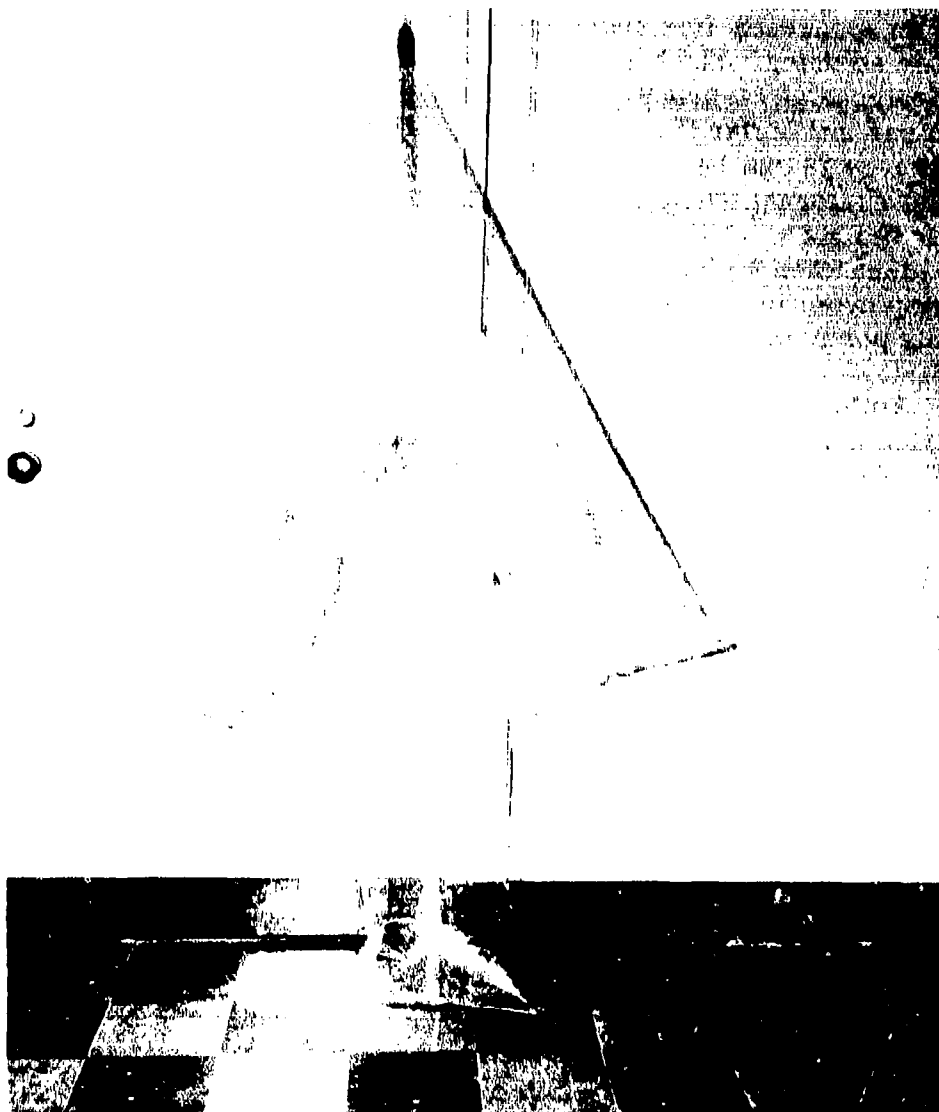


Figure 13. Full-Size Mylar Nose Section (3 Beams)

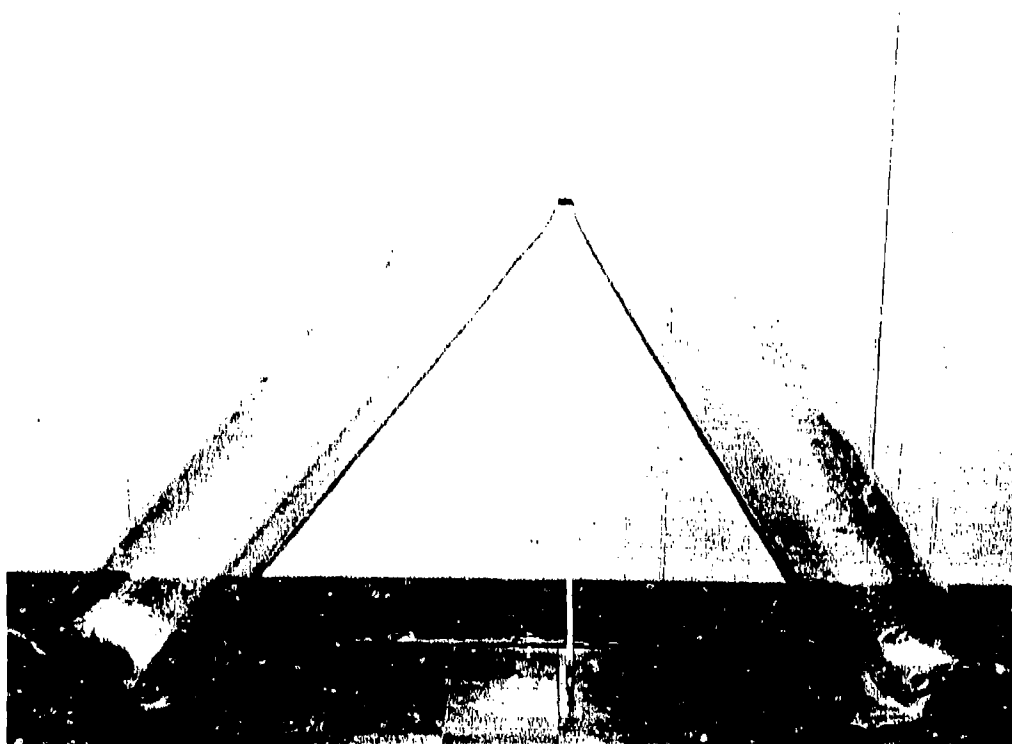


Figure 14. Full-Size Mylar Nose Section (2 Beams)

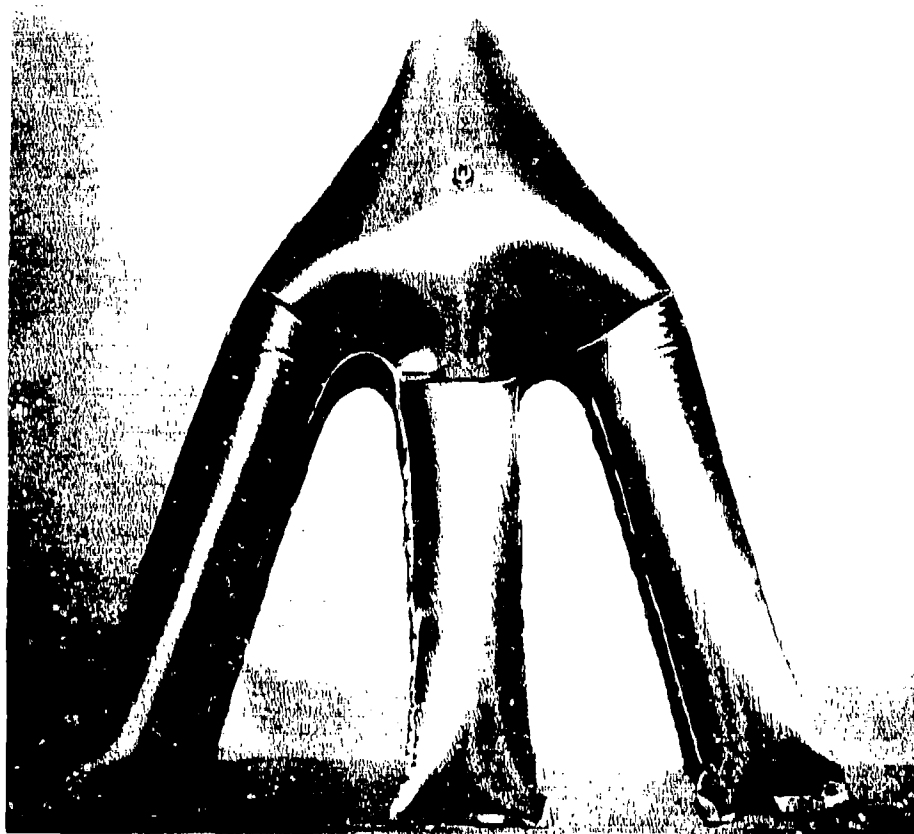


Figure 15. Chloroprene Coated Nylon Model Nose Section

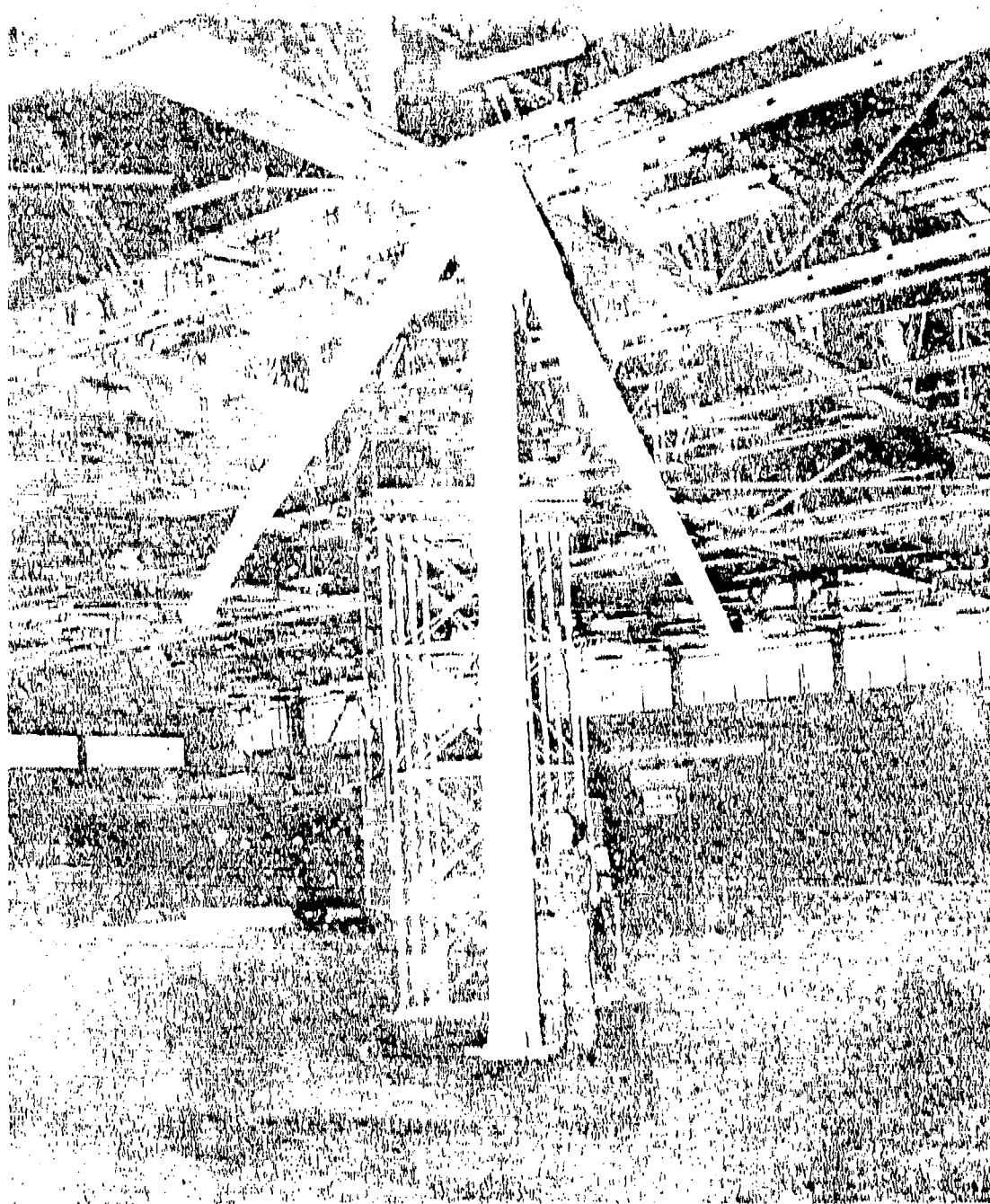


Figure 16. Inflated Paraglider Test Structure

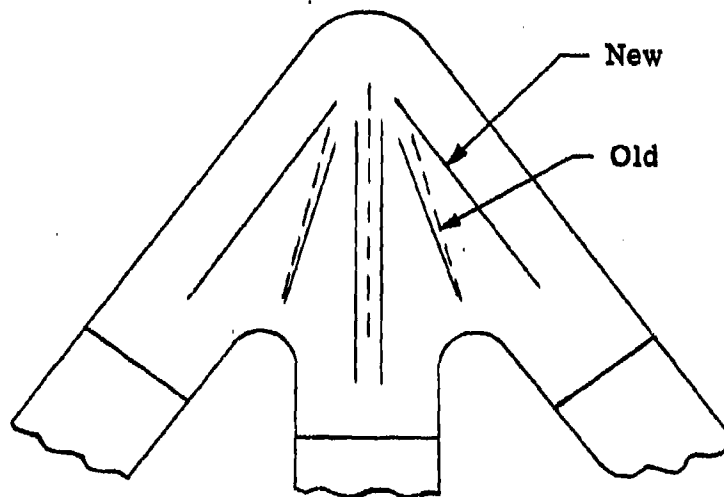


Figure 17. Failure of Paraglider Test Structure

Contracting Officer on 23 February 1962 along with the required drawings. Approval of the configuration for detail design, fabrication, and testing was received on 9 March 1962. Figure 18 is a general arrangement drawing of the approved paraglider design.

Following design approval, a second paraglider inflatable structure was fabricated from heavier neoprene-coated nylon (3 ounces coated to 7.3 oz/sq yd). This action was taken after the lighter material failed several times in hoop tension at approximately 70 percent of tested minimum strength. At this point, it can only be surmised that a small flaw in the material initiated the failure.

Prior to construction of the second structure, we decided to increase the number of tension webs in the nose from three to six. The following sketch shows the old web positions and the new.



The new structure turned out remarkably well as far as shape and planform are concerned. After pressure cycling ten times, the planform was swept back 1.5° more than the 55° design, or a total of 56.5° . The nose shape was much improved over the first model. A photo of the second structure is shown in Figure 19. Some difficulty was encountered with the cemented joints' creeping under pressure. This was traced to an excess of solvent used in the joint cementing process and remedied by a short oven cure at 212°F .

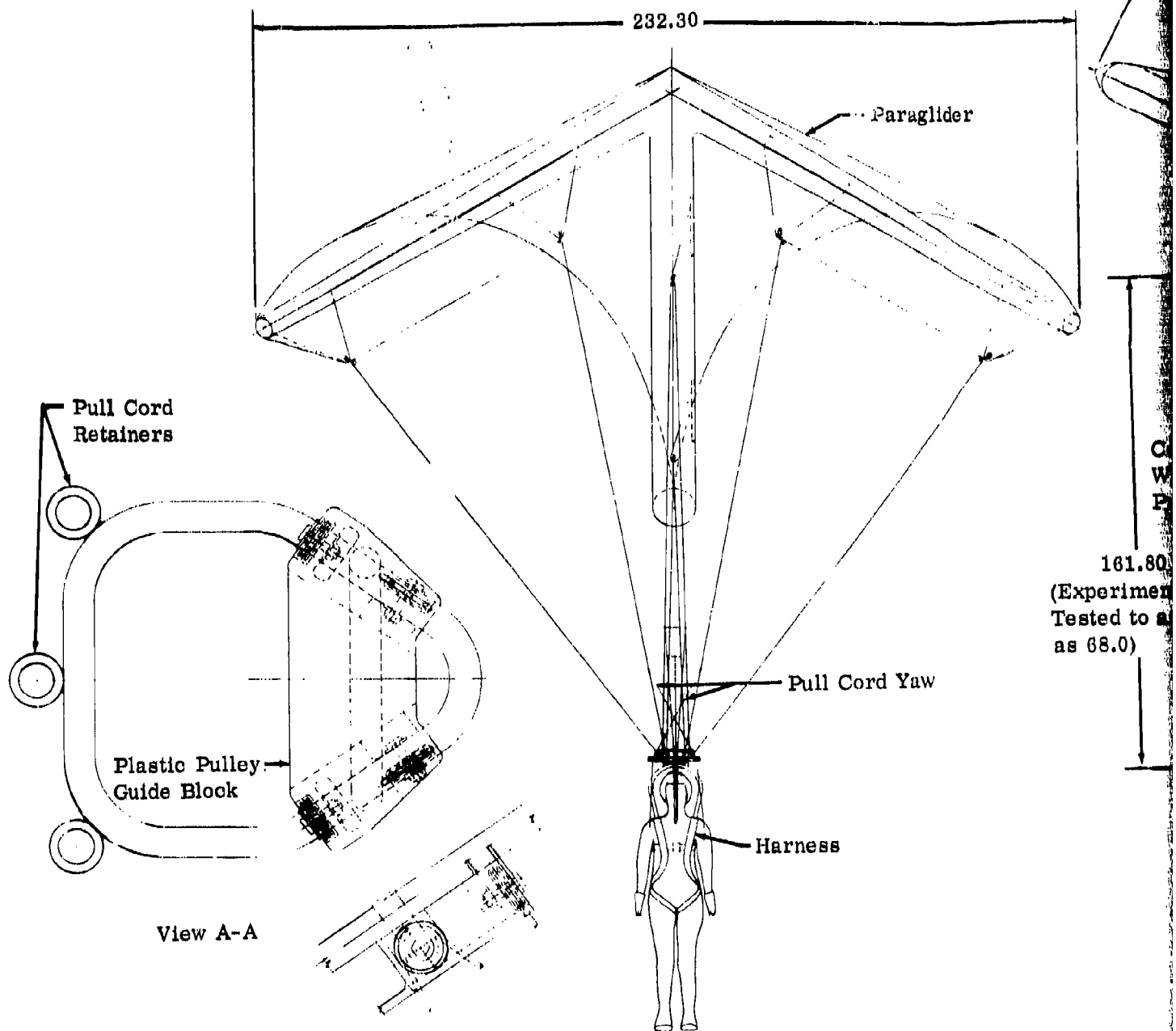
Investigations at NASA, Langley, and throughout the fabrics industry indicated that the lightest weight and best wing material to use was 1.24-ounce rip stop nylon, coated with quarter mil Mylar. This material was used for many paraglider experiments by NASA. During our experiments, it was found to be easily folded and quite durable for our purpose; and although it ripped on several occasions due to localized overloads from wind gusts, we still consider it quite a practical material for this use.

During the control system design period, we considered many different approaches. To expedite the accomplishment of our selected design, we fabricated a full-size wooden mockup of the paraglider for evaluation of various suspension and control systems. Figure 20 is a photograph of this mockup. Three separate suspension control systems are being investigated:

1. A cg shift method whereby the operator propells himself back and forth on rollers or drums to obtain pitch control and simply pulls in the sides for roll control.
2. We planned to evaluate the slip riser method used in the standard parachutes for control. This was not actually done.
3. We devised a continuous rig cg shift system which utilizes one continuous suspension line with pulleys at the juncture of the paraglider, and a pulley block mounted above the man's head on a small mast. It equalizes the tension on all the lines regardless of the operator's position. It appeared to be the simplest practical control system and was the one finally selected for fabrication. A small working model of this system is shown in Figure 21.

Work was begun on the paraglider test harness for attaching the paraglider to the man. It consisted of a modified type T-10 parachute harness with a quick-release feature incorporated. A small mast was fabricated for supporting the pulleys and control lanyards and attached to the parachute harness on each side at the shoulders (Figure 22).

As a result of preliminary captive paraglider tests over land, several structural deficiencies were uncovered and remedial measures taken to prevent their recurrence. The suspension lines were shortened to approximately one-half their original length as a result of this flight testing. The top of the operator's control mast is now 68 inches below the C.P. of the



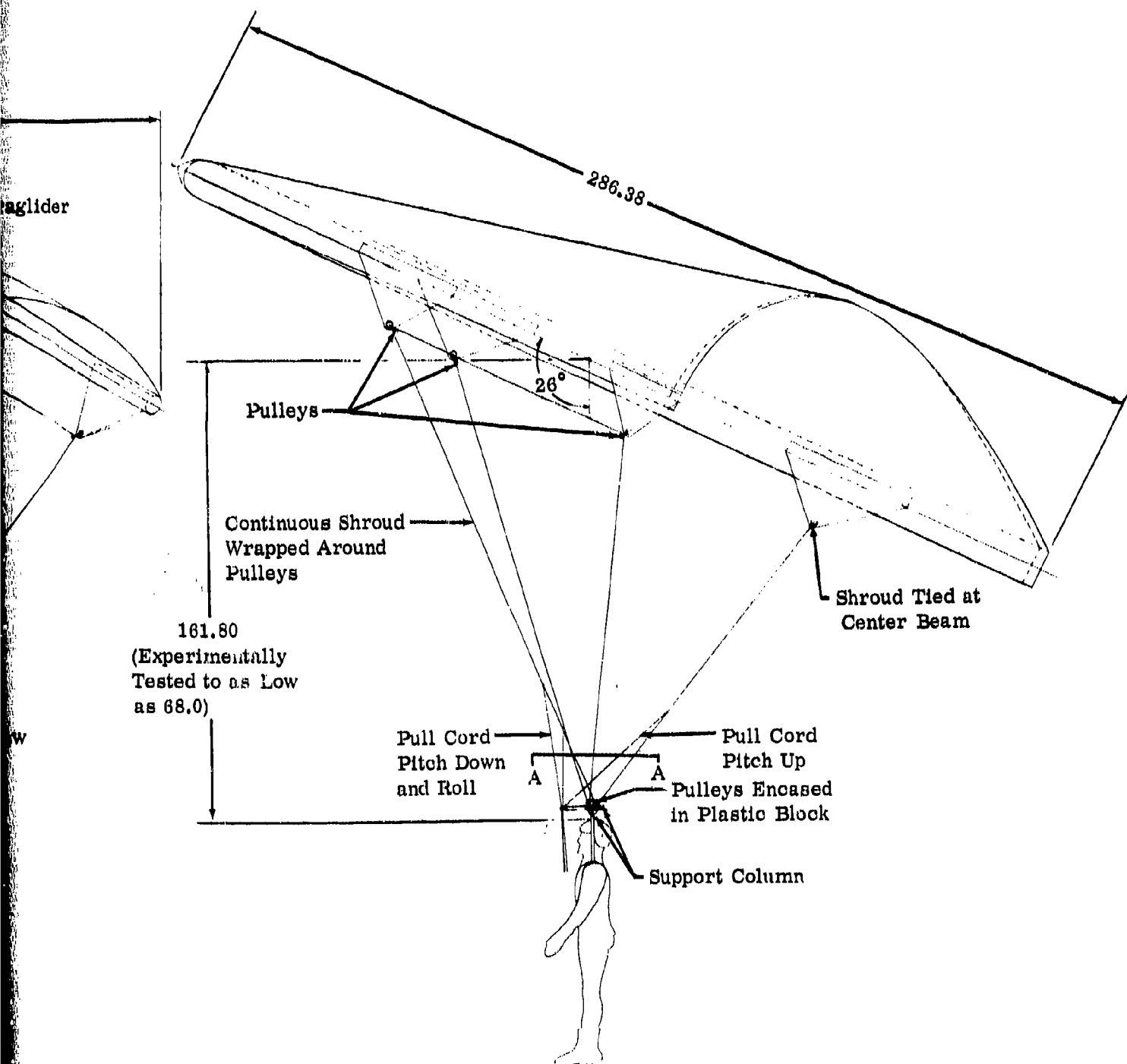


Figure 18. Paraglider General Arrangement

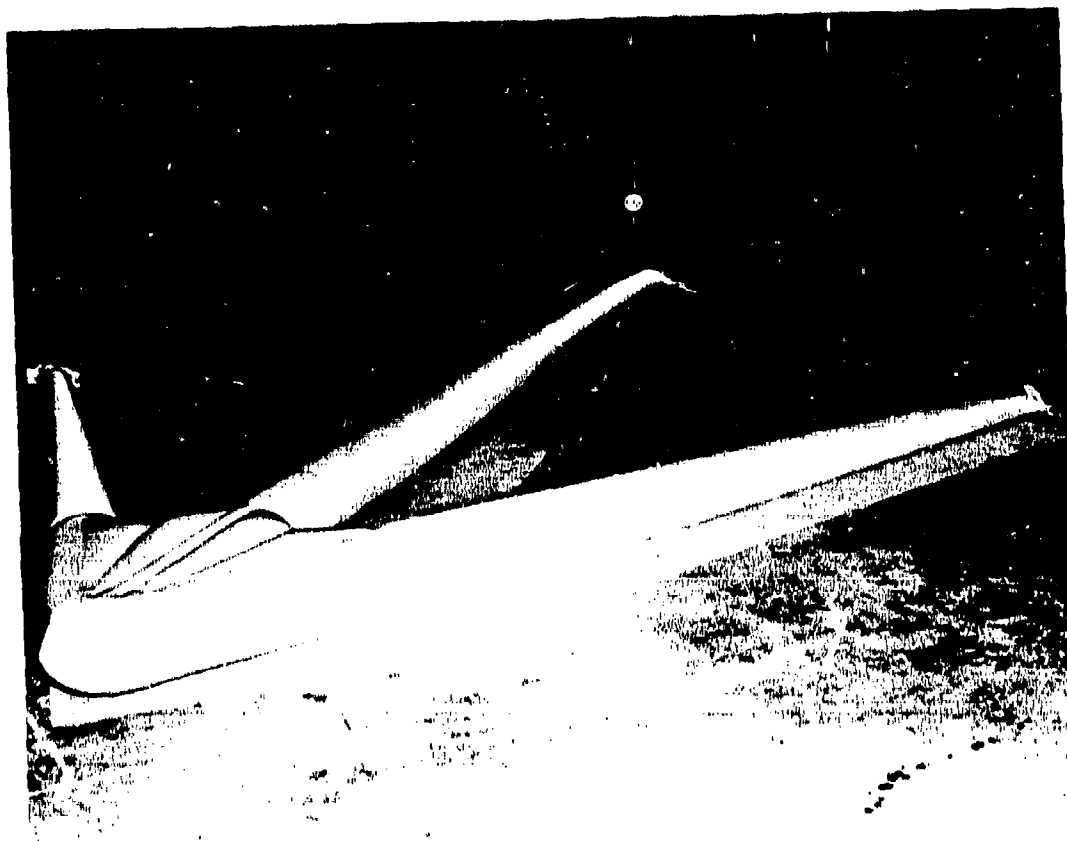


Figure 19. Second Paraglider Structure

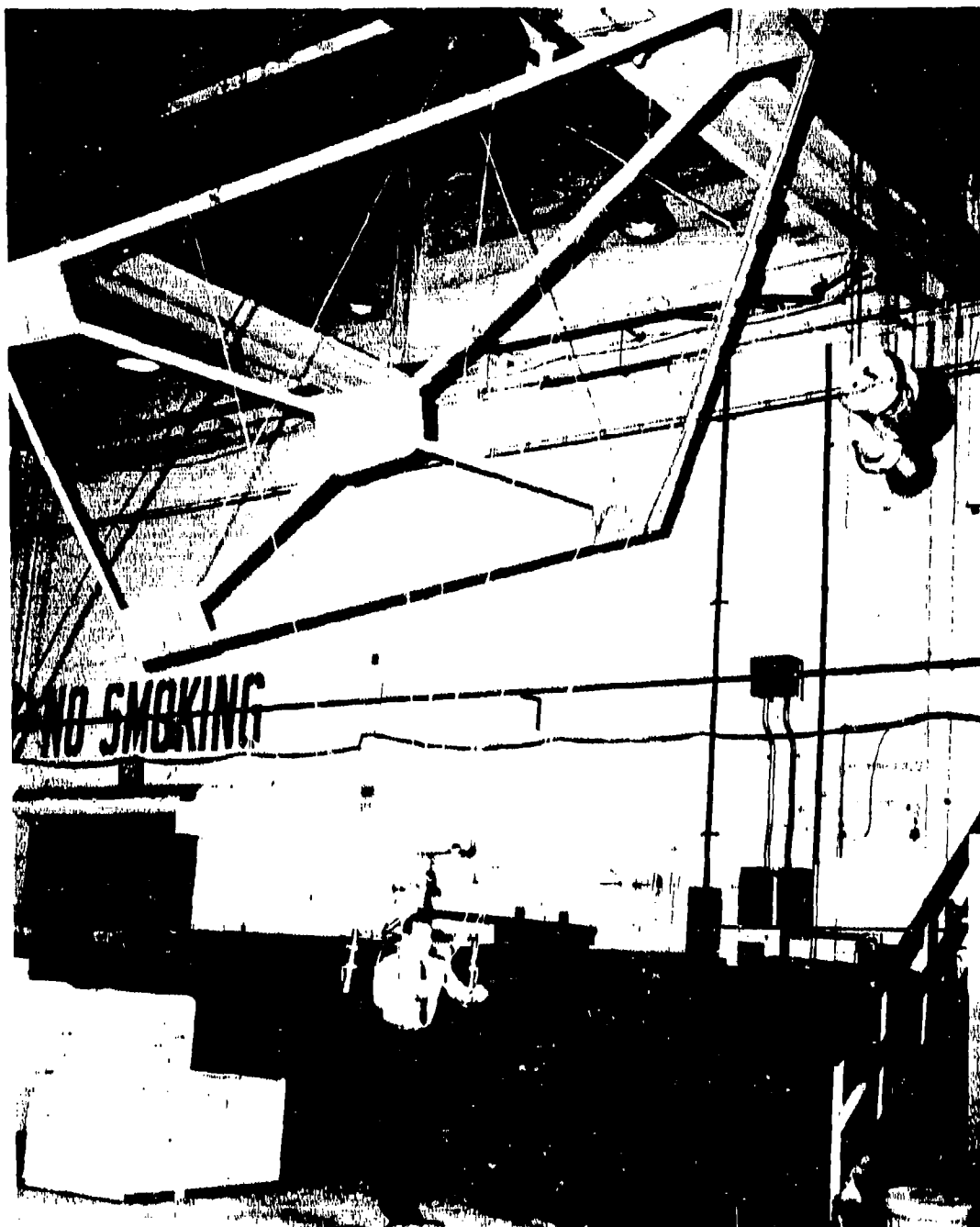


Figure 20. Paraglider Suspension System Mockup



Figure 21. Model, Paraglider Suspension and Control System



Figure 22. Paraglider Harness and Mast Assembly

paraglider. We also worked out a method of towing the paraglider by attaching lines to the center inflated beam only. This obviates the necessity for pulling on the operator and simplifies the towing problem. A quick release mechanism for the operator's end of the tow line was fabricated and installed on the towing system.

Due to our inability to succeed in achieving a towed free-flight launching, this control system was not evaluated as originally planned before the paraglider portion of our program was terminated.

Several methods of paraglider pressurization were considered including the burning of low-temperature solid propellant charges and blowing the discharge gas into the paraglider. This was eliminated because of the nature of the fabric and the possibility of high temperatures causing failures in the structure. The use of nitrogen gas released from the SRLD by a hand valve and plunger inside a thin metal can to eject the paraglider assembly was also considered. This approach was abandoned for several reasons, the most significant being that insufficient gas would remain aboard the SRLD to accomplish this job. Small cartridges of carbon dioxide such as are used in emergency plastic life preservers were investigated for possible use. However, the size and weight of the pressurization system precluded the use of this method; also, carbon dioxide gas in itself is quite heavy when the volume requirements of the paraglider structure are considered. Based on our extensive experience in the rocket propulsion system field, we finally decided that a pressurized stored helium system with a burst disc would probably be the lightest and most reliable method of accomplishing the job. The burst disc could be operated by a manual actuation valve or a tiny electrically operated solenoid valve.

A test gas storage cylinder and quick opening valve assembly was borrowed from another Bell program and set up to do initial packaging and inflation testing from the paraglider structure; nitrogen gas was used for these initial tests. Initial pressure in the cylinder was gradually increased to 1450 psi. During the first seven inflation and deployment tests with this test system, utilizing the originally fabricated lightweight inflatable structure, it was torn twice. Therefore, we installed inflation "arteries" for tubes inside each log to distribute the initial transient pressure more evenly. These inflation arteries worked out very well. No further rupturing or tearing of the structure resulted once these flexible tubes were installed inside the structure.

Following this accomplishment, we retraced our steps and utilized a 1.5 cubic foot gas storage supply to permit us to start at lower storage pressures and gradually work up until we could achieve a minimum inflation time. The initial deployment with a 1.5 cubic foot bottle started out at 500 psi and required 1.5 minutes to unfold the structure and inflate it. Several more tests of this standard bottle indicated that the outlet orifice permanently machined in the cylinder valve was too small to accomplish our purpose. Following this, we utilized two lightweight fiberglass spheres, each having a capacity of 1/6 cubic foot. With these manifolded, we were able to install a quickly removable orifice which could be changed in size as we proceeded with the test. As of this date, these bottles have been successfully charged to 2000 psi and have inflated the paraglider structure through the small orifice in 22 seconds. This was the best time achieved prior to termination of this effort. After a short study, the packaging technique used was that of folding the three deflated spars or "logs" together in parallel fashion. These were then rolled (to make a minimum sized package) from the nose to the center and from the tail to the center. The actual inflation fitting was then installed from the bottom center of the middle spar which would permit a vertical line to come up from the SRIID when and if the paraglider were perfected. When the gas was released, the middle spar would inflate first, followed by the two outer leading edge spars.

Due to our structural fabric difficulties, we fell behind our originally planned paraglider schedule; and after numerous experiments, the original plans for fabricating a rigid paraglider for preliminary tests with water skis were abandoned. It was mutually agreed with TRECOM that we would learn more and accomplish the end goal more quickly by building two inflatable paragliders instead of one rigid one. Plans to test the paraglider in Florida were finally abandoned in favor of local testing on Lake Ontario. Due to the low water temperature (41°F), we purchased three wet skin-diving suits to protect the operator and test crew from exposure. We fabricated a tow test platform utilizing two aircraft tip tanks as floats and a rubber covered plywood platform for support of the operator and paraglider in launch position. An inboard power boat was rented for towing purposes on an as-required basis.

Due to the difficulty encountered with the rubberized nylon structure material, we doubled its thickness and therefore its weight. This and other small incremental increases on sail flaps and tow lines greatly increased the originally estimated weight of the Mylar paraglider as well as the package bulk. A general weight breakdown of the complete

assembly, as finally designed when the project was terminated, was as follows:

Glider	11.5 lb
Sail	9.5
Two fiberglass spheres plus release valve	10.0
Mast and lines	3.0
Total	<u>34.0 lb</u>

At this point, it appeared that if we were going to achieve a packaged paraglider small enough and light enough to demonstrate with the rocket belt, we were going to have to revert to a different, lighter and more reliable material for the inflatable structure.

B. CAPTIVE FLIGHT TEST PROGRAM

On Friday, 6 April 1962, the preinflated paraglider was flown for the first time as a kite without a man aboard. Figure 23 is a photo of the paraglider in captive flight. After our arrival at the test site, the wind velocity had increased to a minimum of 20 knots; therefore, only one captive flight and handling techniques were investigated on this first session. Several shortcomings were observed at this time. The nose portion of the sail did not exhibit the proper contour in flight. This is apparent in Figure 23. Secondly, the sail tore at the forward corners of the forward suspension line tabs on both left and right leading edges. Analyses indicated high local stresses due to the loads being dumped into the fabric from the corners of the tabs. The sail nose contour was reworked to conform to design configuration. Four internal, snugly fitting sleeves were installed inside the sail-to-structure attachment loops to distribute these loads in a more even manner. The following sketch shows the sleeve installation:

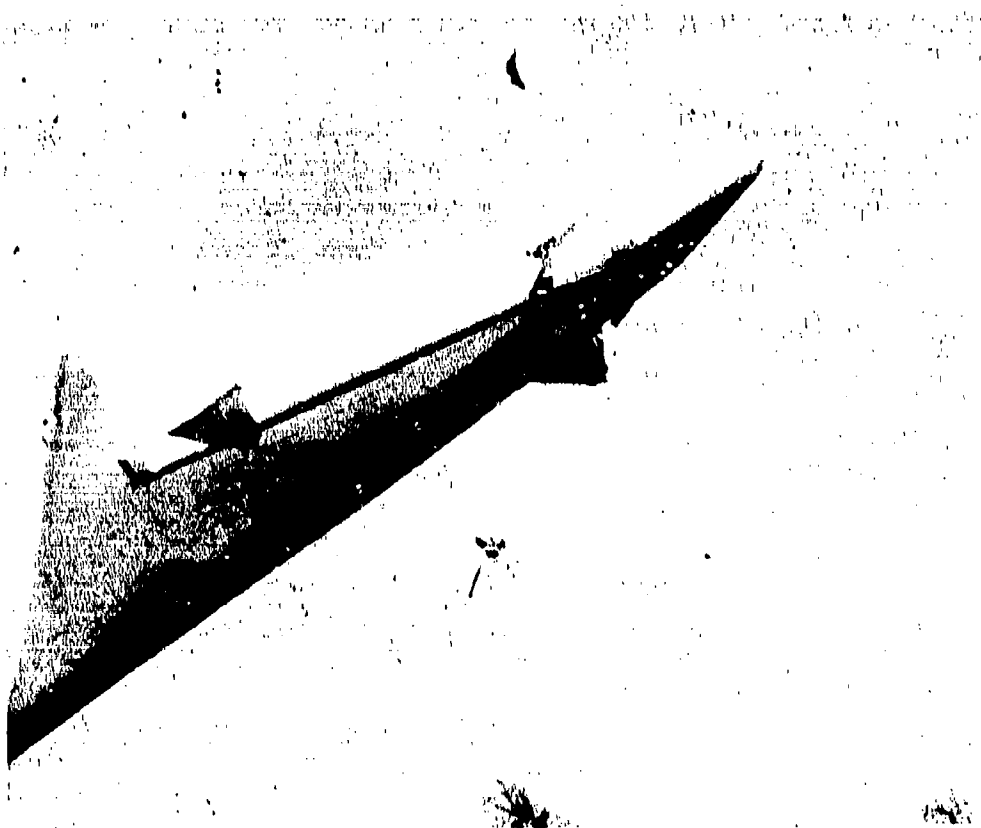
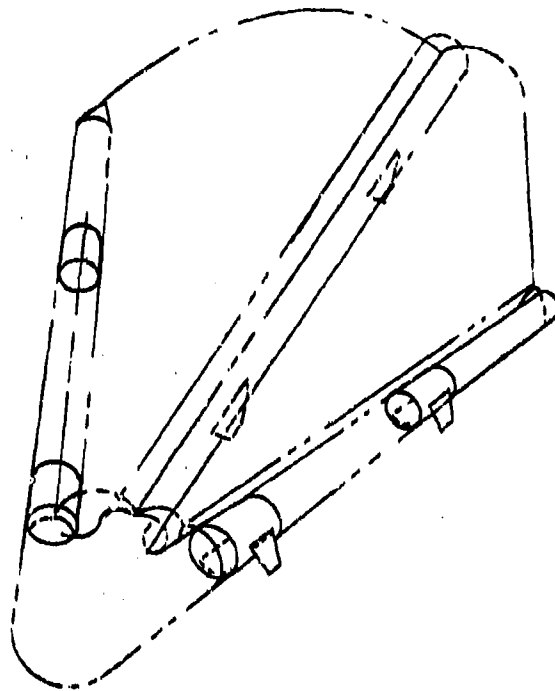


Figure 23. Paraglider in Captive Flight



During the course of these over-the-ground preinflated paraglider test launchings, a total of 24 attempts were made. A manned paraglider flight of 210-foot distance and 40-foot altitude was achieved by towing with an automobile. Two pictures enlarged from movie frames of the over-land paraglider tow tests are shown in Figure 24. The top picture is an unmanned captive flight and the lower one is a manned operation with the operator at lift-off.

During these flight sessions, considerable difficulty was encountered with maintenance of a secure pressurized structure. Such objects as small stubs of heavy weed stems from field cuttings would puncture the frame-work quite readily.

The first 19 flights were either hand towed or flown statically. Changes were made in the load and tow support lines as were deemed necessary to obtain a smooth lift-off and maximum load capabilities.

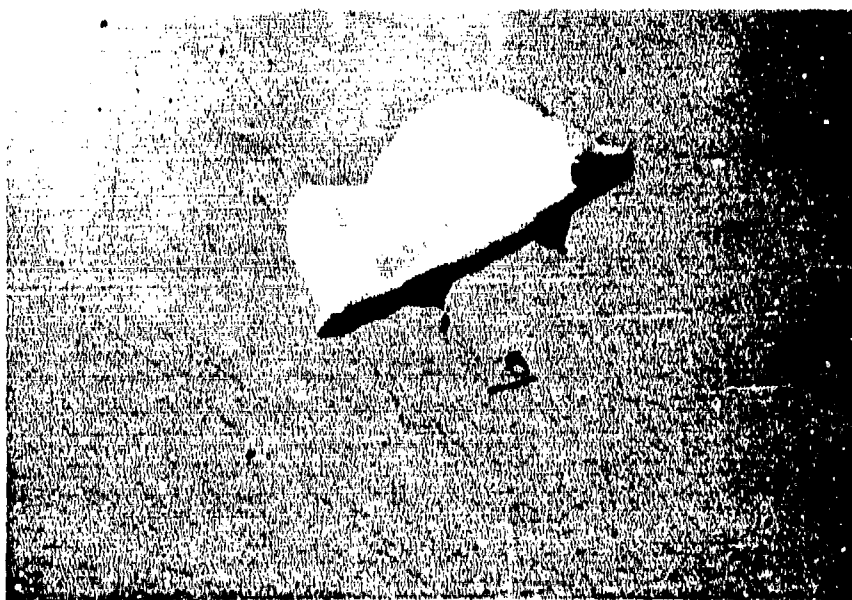
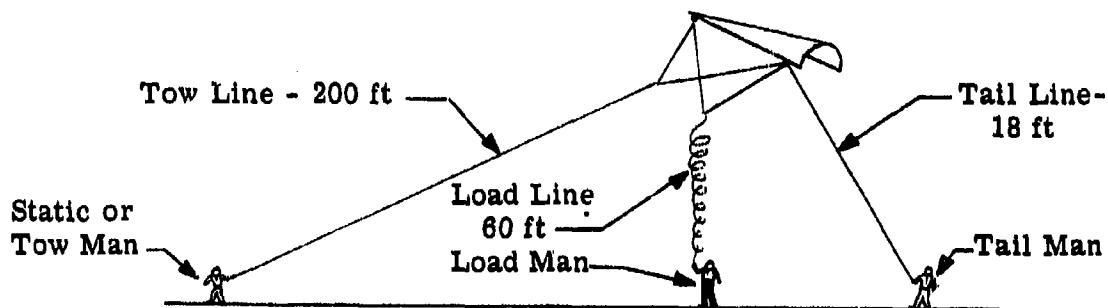


Figure 24. Paraglider Tow Tests - Manned and Unmanned

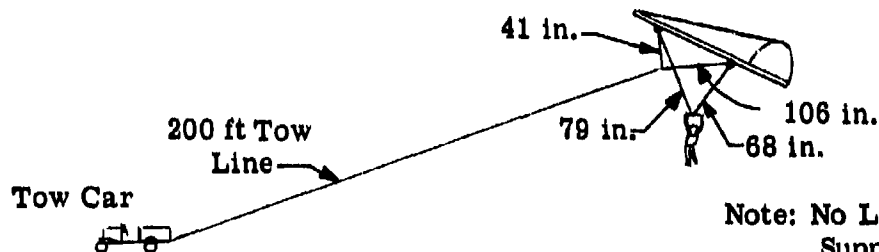
The static tests (air speed equals wind velocity) were performed in two stages. At lift-off, a tail control man guided the paraglider (preventing lateral roll) up to an altitude of 18 feet at which point the load man took over, easing the paraglider up to an altitude of sixty feet. The following sketch depicts this operation.

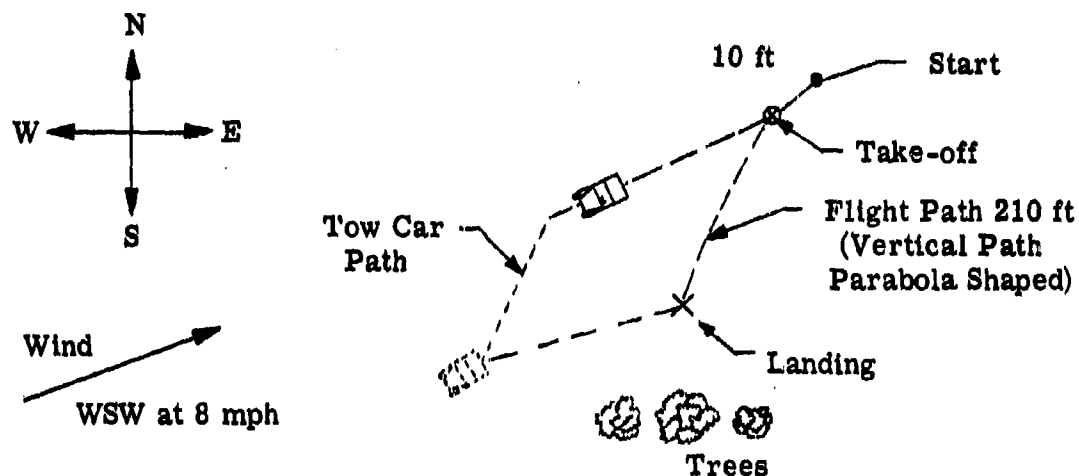


On the seventeenth static flight test (wind velocity, 21 mph), the 160-pound load man was lifted to an altitude of thirteen feet. After two seconds of flight at this altitude, the tow support lines and two load support flaps failed, flipping the paraglider over on its back. The following corrective actions were taken:

1. All flaps were double-reinforced with fabric.
2. Bulbous aluminum flap bars were installed as replacements for the flat plates.
3. New load and tow support lines were installed.

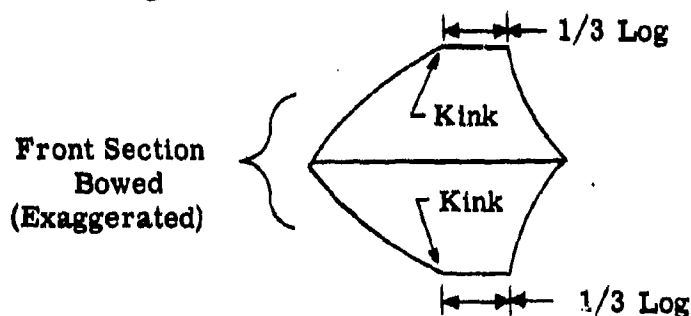
Flights 20 through 24 were car towed. The data from the first successful manned flight (23) are as follows:





Notes:

1. Angle of attack at lift-off = 70° .
2. Angle of attack at altitude and during descent = 50° .
3. Paraglider inflation pressure = 2 psig.
4. Outboard logs were kinked as follows:



As a result of these 24 flights, and the altitudes and speeds involved with a human operator airborne, it was decided that we were taking unnecessary risks to proceed beyond this point over the land. Consequently, we performed the remaining paraglider tow tests over the waters of Lake Ontario and the Niagara River.

The initial six water launch test sessions were accomplished over the waters of Lake Ontario and the Niagara River. Results of these water tow tests were rather disappointing. Difficulty was encountered launching the paraglider from the towed float due to the inability to properly position the paraglider and the operator prior to lift-off. Much of this difficulty was due to the extremely light wing loading and the handling characteristics of the large-size paraglider. We did, however, accomplish one successful towed unmanned launching. As a result of the difficulty with the float at this time, we purchased a pair of water walking shoes, which we modified by tying them together and installing a rest seat upon which the operator could sit. This was towed with a man aboard by a power boat quite successfully without involving the paraglider. However, we later widened the floats in order to permit more lateral stability when the paraglider was to be added. Actually, these water walking shoes were never used with the paraglider. We reverted to the use of our floating platform with revised paraglider holding fixtures. This launch system is shown in Figure 25. On the ninth and last test session with the power boat and float arrangement, we succeeded, by putting two men on the float, to actually air launch the paraglider without a man aboard. However, after approximately 200 feet of towing, the paraglider keeled over to the left side and landed in the water. At this time, it was severely torn when it collided with a piece of partially submerged flotsam.

Again during the water testing session, we had continuing difficulties with leaks in the pressurized neoprene-coated structure. The leaks were caused by shore scuffs, seams creeping, and by pin holes showing up after it had been inflated several times, as well as small snags encountered by hitting sticks, etc., in the water when it landed.

It appeared at this time that the majority of our problems were centered around handling and launching over water and/or land. These particular problems were not those which would be encountered when the paraglider was to be used with an SRLD. Therefore, we seriously considered abandoning the water-tow-launch test method in favor of dropping the preinflated paraglider with a rubber body block from a parachute tower at Fort Benning.

As a result of the foregoing problems, and other considerations involved, during this preinflated flight testing phase, a conference was held at TRECOM to re-evaluate this part of the program. As a result, further work on the SRLD paraglider was stopped.



Figure 25. Preinflated Launch Techniques Over Water

In summary, three towed manned flights were achieved over land. The maximum altitude achieved was approximately 40 feet at an air speed of 20 to 25 miles per hour. The folding and deployment technique was developed to the point of unfolding and inflating the structure only in 22 seconds with 2000 psi nitrogen from storage bottles. A control system and a harness - control mast were designed and fabricated but not flight tested sufficiently to evaluate them. Leakage from the inflatable structure material and preinflated launching troubles were the biggest problems encountered at the time of termination of work. Further, results of packaging and deployment test at that time pointed to even greater problems than the aforementioned ones.

1. Aerodynamic Performance

A considerable amount of time was devoted to an evaluation of the merits of a paraglider wing as a means of lift augmentation for Bell's SRLD. Lift augmentation of this nature was expected to accomplish:

- a. Extended range, and
- b. Safety during operation.

The results of our studies indicated that, with the proposed configuration, both of these objectives could be achieved. The design factors that were influential in the selection of this configuration, as well as the procedure followed in the determination of its aerodynamic performance, are discussed in subsequent paragraphs.

The information pertinent to the design of the paraglider was obtained during a visit to NASA at Langley Field, Virginia. A compilation of this information is given in Appendix I. Some of the more desirable features of various models investigated by NASA were either incorporated or considered in our final design. These include:

- a. A leading-edge sweep of 55° and a square fabric area. This combination provides good directional stability for both towing and free-flight conditions plus good lift-to-drag ratios $((L/D)_{\max} = 4.7 \text{ for paraglider above})$.
- b. A leading-edge diameter no greater than 5 percent of the leading-edge length.

- c. A trailing-edge hem to permit insertion of a bolt rope should bolting become necessary from the standpoint of obtaining an increased L/D and/or as a means of pitch control.

The aerodynamic information for an equal sided, 55° sweep paraglider, as shown in Figure 26, served as the basis for the performance calculations.

- a. An estimation of the effect of nose rounding on the aerodynamic characteristics of the paraglider was achieved by arbitrarily subtracting a value of $\Delta (L/D) = 0.1$ from the L/D curve of Figure 26, which applies strictly to a sharp nose.
- b. The frontal area and the drag coefficient (based on this frontal area) of the man plus equipment harness and shroud lines were estimated as 10 ft² and 1.5 respectively, based on the information of Reference 1. Referring this coefficient from the frontal area to the paraglider reference area (285 ft²) and using the information of Figure 26, the variation of the system L/D with angle of attack was calculated. The results are shown in Figure 27.

An examination of Figure 27 shows the maximum L/D of the final design to be 3.24 at an angle of attack of 26°. Performing calculations based on this design are shown in Figure 28 using the information of Figure 27. The results indicate that, operating at maximum L/D, ($\alpha = 26^\circ$), and at a gross weight of 285 pounds, the forward velocity along the flight path will be 38.8 fps. The vertical component of this velocity will be approximately 11.5 fps, which compares favorably with the vertical descent rate of 15 to 20 fps being experienced by present-day paratroopers. The horizontal component (37 fps) of the velocity (38.8 fps) along the flight path is equivalent to approximately 25 mph. This, too, is less than the maximum wind conditions (up to 30 mph) to which a parachute may be subjected during the descent. Aside from these landing considerations, the paraglider, due to its high L/D, has the definite advantage in range. Therefore, the proposed design, neglecting any need for flaring, already equals and exceeds the operational limits of a parachute from the standpoints of landing velocities and range, respectively.

Running tests conducted at Bell indicated that a fully equipped man at an approximate weight of 285 pounds should be able to maintain his balance provided that the horizontal component of the landing velocity does

1. Equal Sided
2. Sharp nose
3. Sweep = 55°

— NASA Data
 - - - Estimated

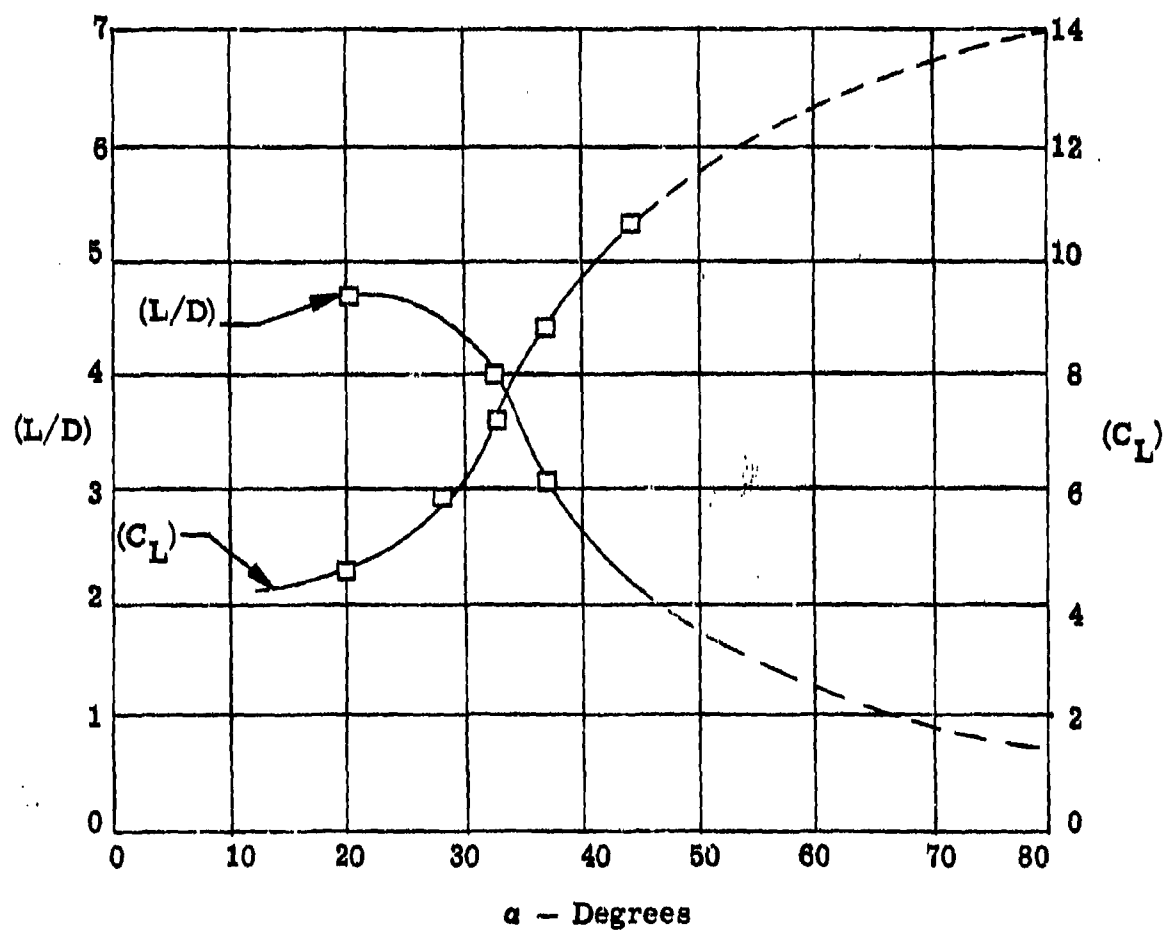


Figure 26. Paraglider Performance

1. Rounded Nose
2. $\Lambda = 55$ Degrees

— NASA Values
 - - - Estimated

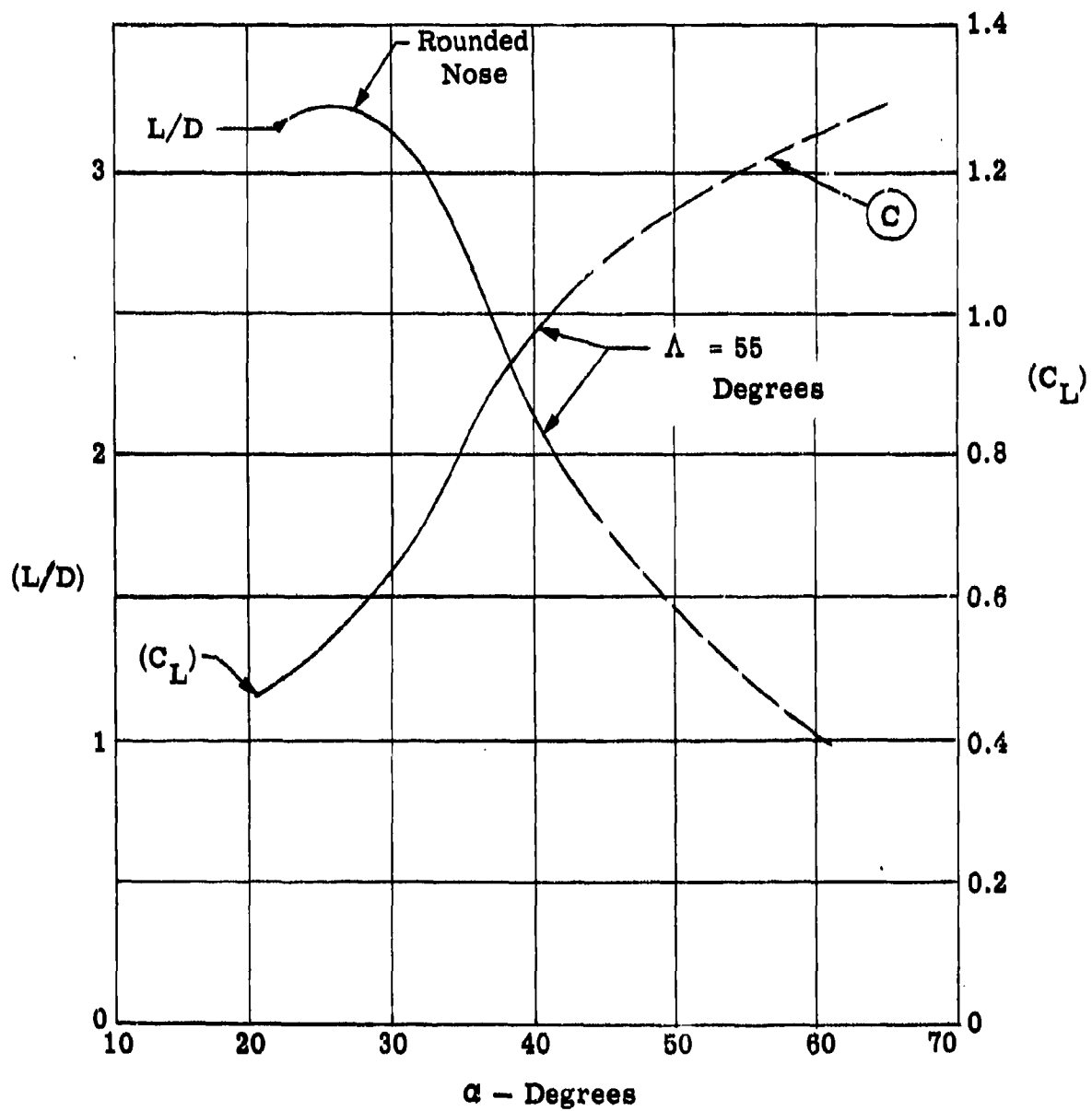


Figure 27. Manned Paraglider Performance

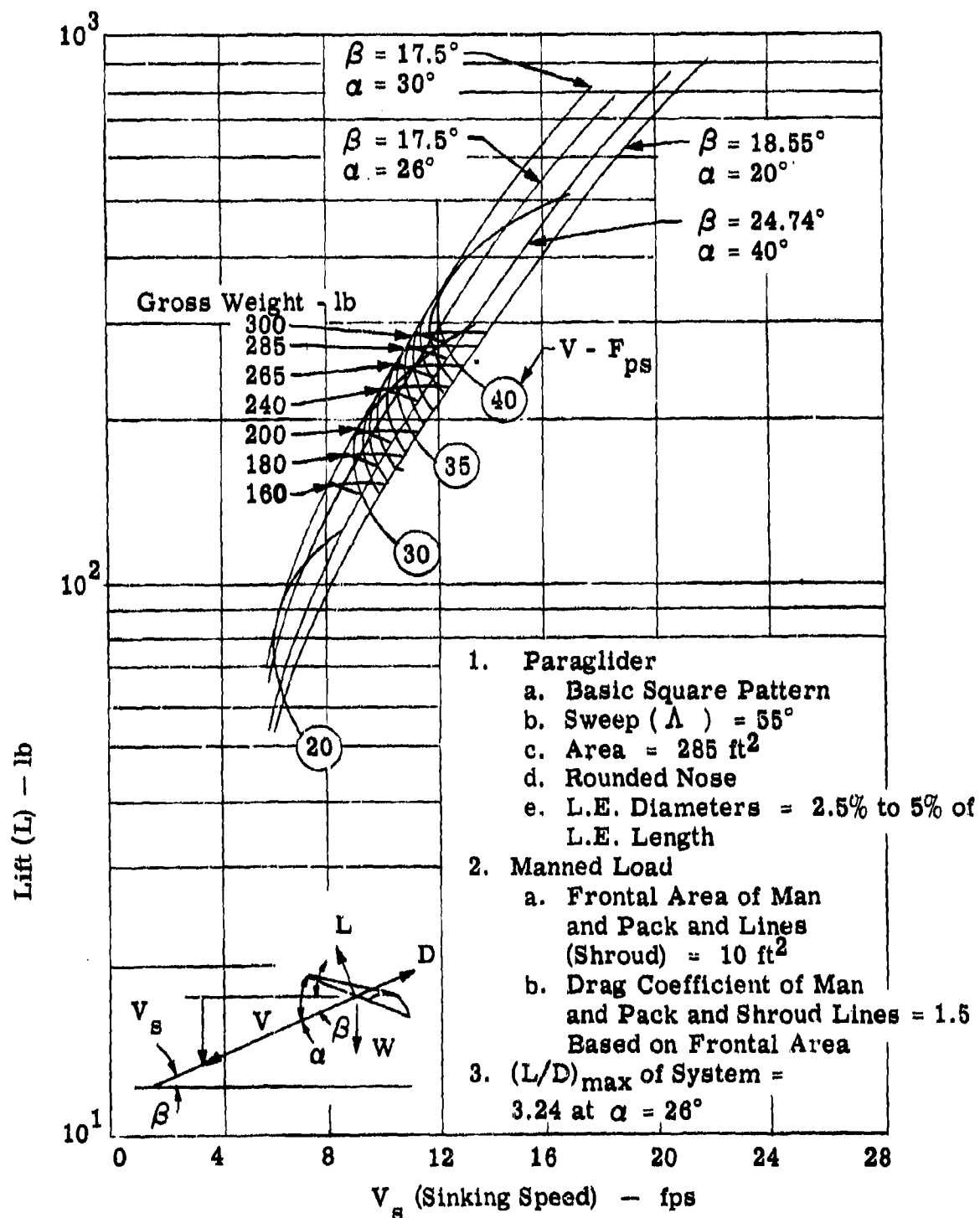


Figure 28. Manned Paraglider Performance - Glide Version

not exceed 18.5 fps. Since this condition could possibly be achieved by flaring prior to touchdown, an IBM program was set up to determine the flare patterns for two different system weights (180 and 285 pounds) and three different rates of flare ($6.25^\circ/\text{s}$, $12.5^\circ/\text{s}$ and $25^\circ/\text{s}$). These results are shown in Figures 29 and 30 where the conditions at the "start of flares" are the maximum L/D glide conditions of Figure 28, for the particular weight being considered. Maximum angle of attack during flare was restricted to a value somewhere between 60° and 65° , since it was believed that the reliability of values obtained from any further extrapolation of information of Figure 26 beyond this region would be rather questionable. The solid symbols in Figures 29 and 30 indicate the points on the trajectories (each at a different rate of flare) where the minimum velocity occurred along the flight path. The time increments between each machine calculation (noted by a symbol) for the rates of flare of $6.25^\circ/\text{s}$, $12.5^\circ/\text{s}$, and $25^\circ/\text{s}$ were 0.4, 0.2, and 0.1 second, respectively. Thus, the change in angle of attack between each calculation was 2.5° . The results of Figure 29 indicate that at a gross weight of 285 pounds, the landing velocities would vary from 18.8 to 19.45 fps for the different rates of flare. The corresponding horizontal components of these velocities are all about 17 fps, indicating that a fully equipped man could be safely landed with a paraglider of the proposed design. Therefore, the requirements of range and safety as previously set forth would be attained by an operation at maximum L/D during glide descent and a flare maneuver just prior to touchdown. The dashed portions of the curves are the estimated values of C_L and L/D at the higher values of angle of attack.

The determination of the lift and drag characteristics for the entire system (man plus equipment and paraglider) will be described in the step-by-step manner in which it was conducted.

- a. The first step was the selection of paraglider size. In addition to the requirement that it must be capable of being packaged within a small container, indications were that the paraglider should have ample size such that the wing loading would be equal to or less than 1 lb/ft^2 . This provision guarantees reasonably landing velocities after the completion of a flare maneuver. A wing area of 285 ft^2 was selected, resulting in a wing loading of 1.00 lb/ft^2 when based on a system gross weight of 285.

1. No gusts or winds
2. G.W. = 285 lb
3. S = 285 sq ft
4. At start of flare
 - a. $V = 38.8$ fps
 - b. $\alpha = 26^\circ$; $\gamma = 72.85^\circ$; $(L/D) = 3.24$; $\Lambda = 55^\circ$

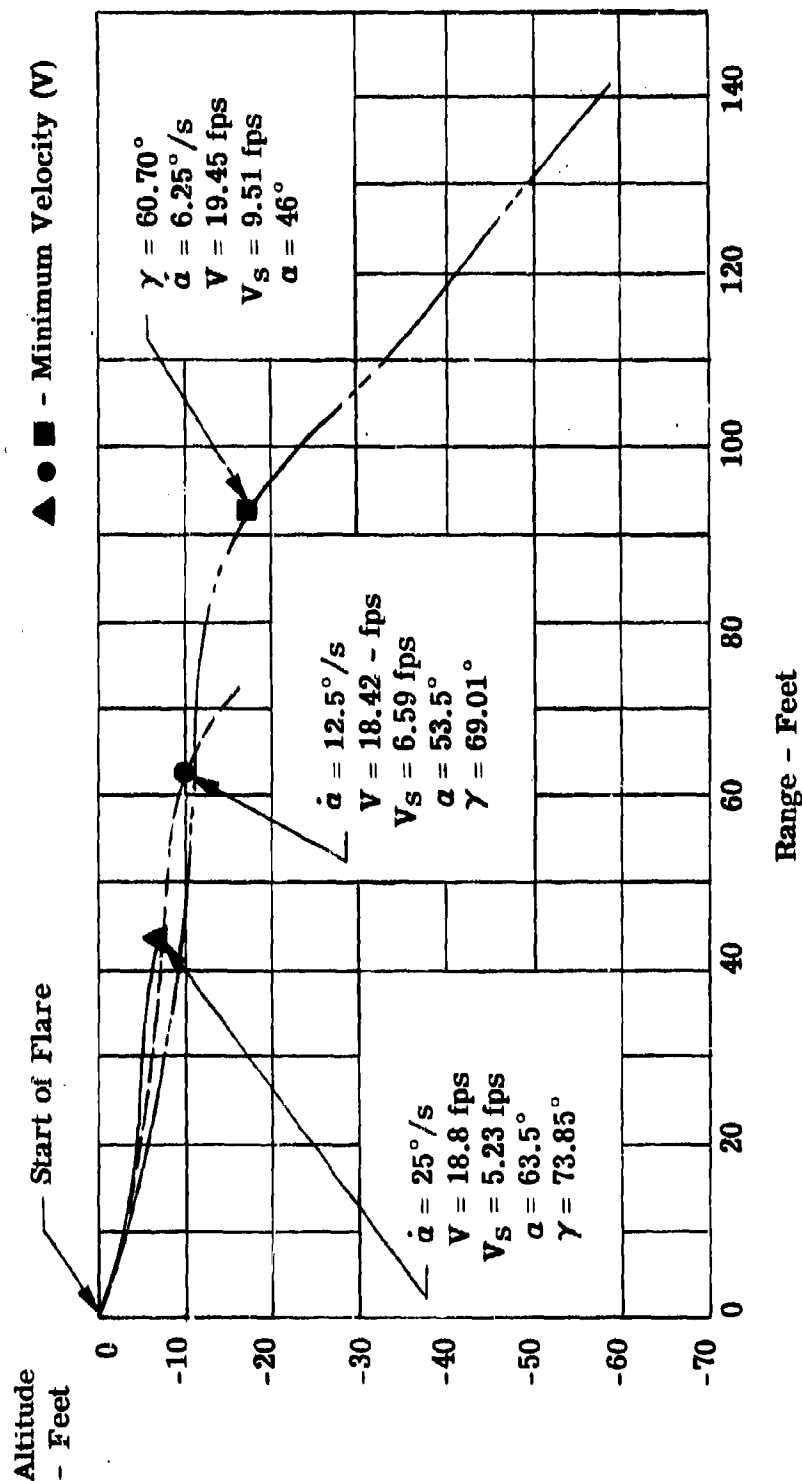


Figure 29. Paraglider Flare Trajectories

1. No Gusts or Winds
2. G.W. = 180 lb
3. S = 285 sq ft
4. At Start of Flare
 - a. $V = 31$ Fps
 - b. $\alpha = 26^\circ$; $\gamma = 72.85$; $(L/D) = 3.24$; $\mu = 55^\circ$

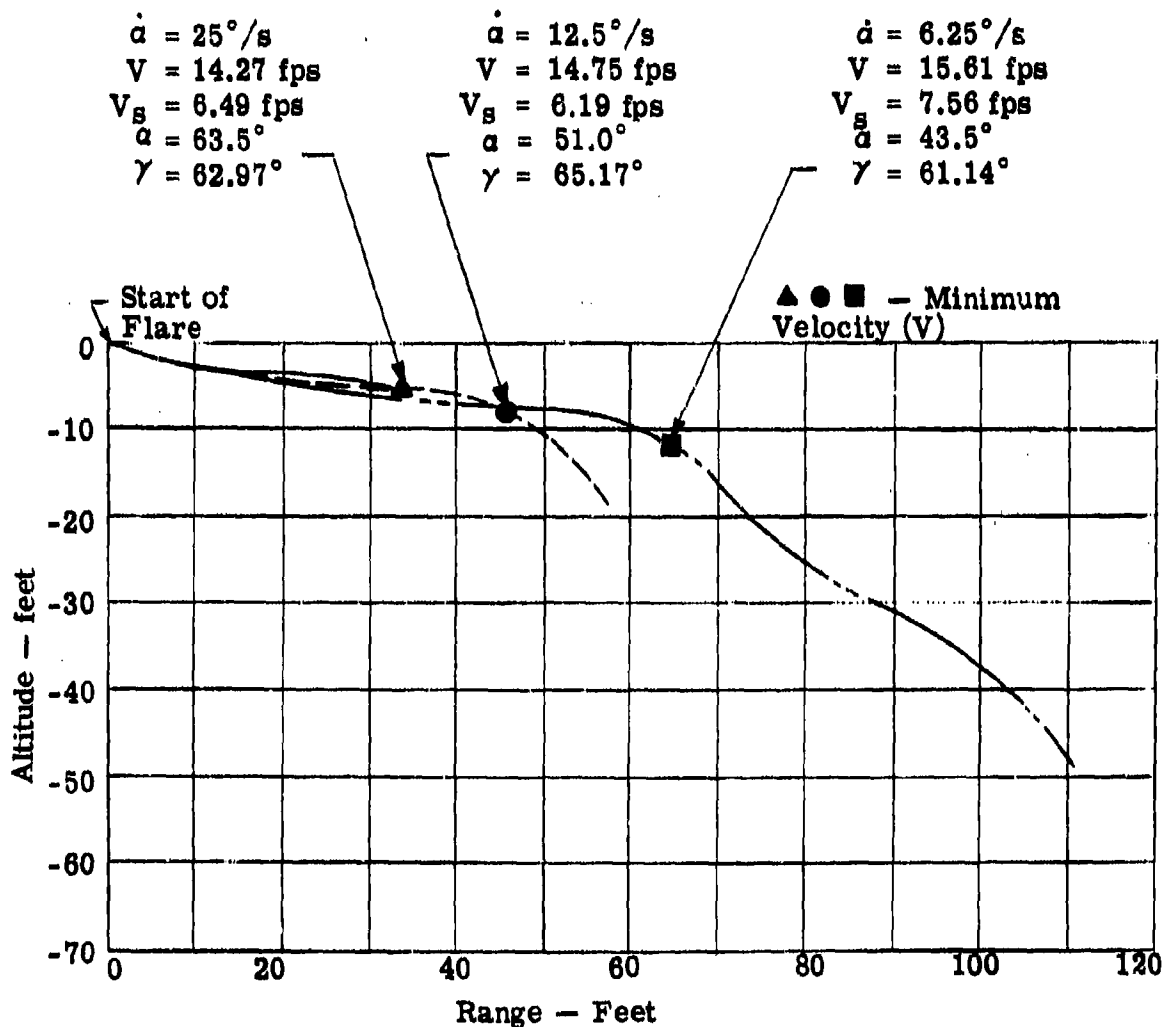


Figure 30. Paraglider Flare Trajectories

- b. As stated previously, the in-flight sweep angle was chosen as 55° and the basic fabric pattern as a square. The reason for selecting a square pattern as opposed to an equal sided pattern (when leading edges and the keel are the same length) stemmed from the fact that NASA tests indicated an increased directional stability (L/D) for the former at the same sweep angle. It should be noted that the aerodynamic information of Figure 26 applies to an equal sided paraglider; hence, subsequent glide performance results may be slightly conservative.
- c. The leading-edge diameters were chosen to vary linearly from 2.5 to 5 percent of the leading edge length from the rearward to the forward end of the leading edges, respectively. The selected keel thickness was 5 percent of the leading edge length.

2. Aerodynamics of Launch

A study was also conducted into the problem of launching the manned paraglider system. The initial step in testing the full-scale model would be an attempt to fly the system by hand towing it into a sufficiently strong ground wind. With a fixed angle of attack setting of 26° , the paraglider alone should become airborne at approximately 6.25 mph. Calculations conducted so far indicate that if the angle of attack is maintained at 26° and the velocity, relative to the paraglider, is increased to approximately 32.55 fps (22.2 mph), the entire system will become airborne. It was expected that this type of towing arrangement could, at best, provide only a few moments of actual flight. However, it was expected to provide some valuable information regarding the proper location of the tow-line attachment point during that period of the launch when the shroud lines are supporting only a fraction of the operator's weight. Under these conditions, the lines lack the rigidity necessary for the rigid system assumption, which has been conveniently employed in our towing studies of a completely airborne system. The results of these studies, as shown in Figures 31, 32, and 33 define the towing angle, the tow-line attachment point, and the tow-line tension required to sustain a 175-pound system in equilibrium (in the pitching plane) for various towing velocities. Of particular interest is the fact that the tow-line attachment point is very sensitive to the towing velocity. During launch, when the wing is supporting only a portion of the operator's weight, the air drag on the operator is cancelled by the frictional force between the operator's

Total Wt (W) = 175 lb
 Wing Sweep = 55°
 Wing Area = 285 ft^2

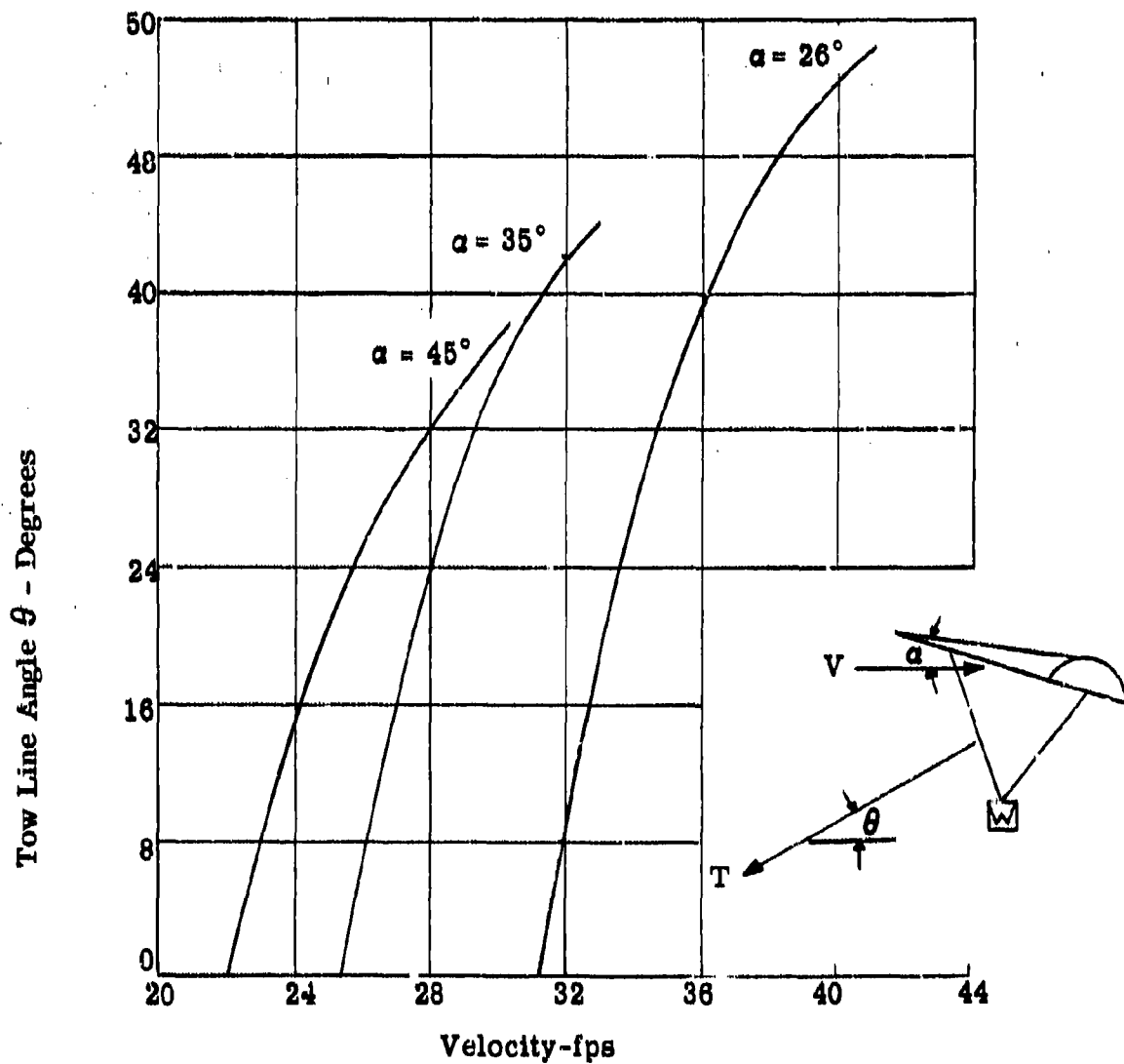


Figure 31. Towing Velocity Versus Towing Angle For Stable Flight

Total Wt (W) = 175 lb
 Wing Sweep = 55°
 Wing Area = 285 ft²

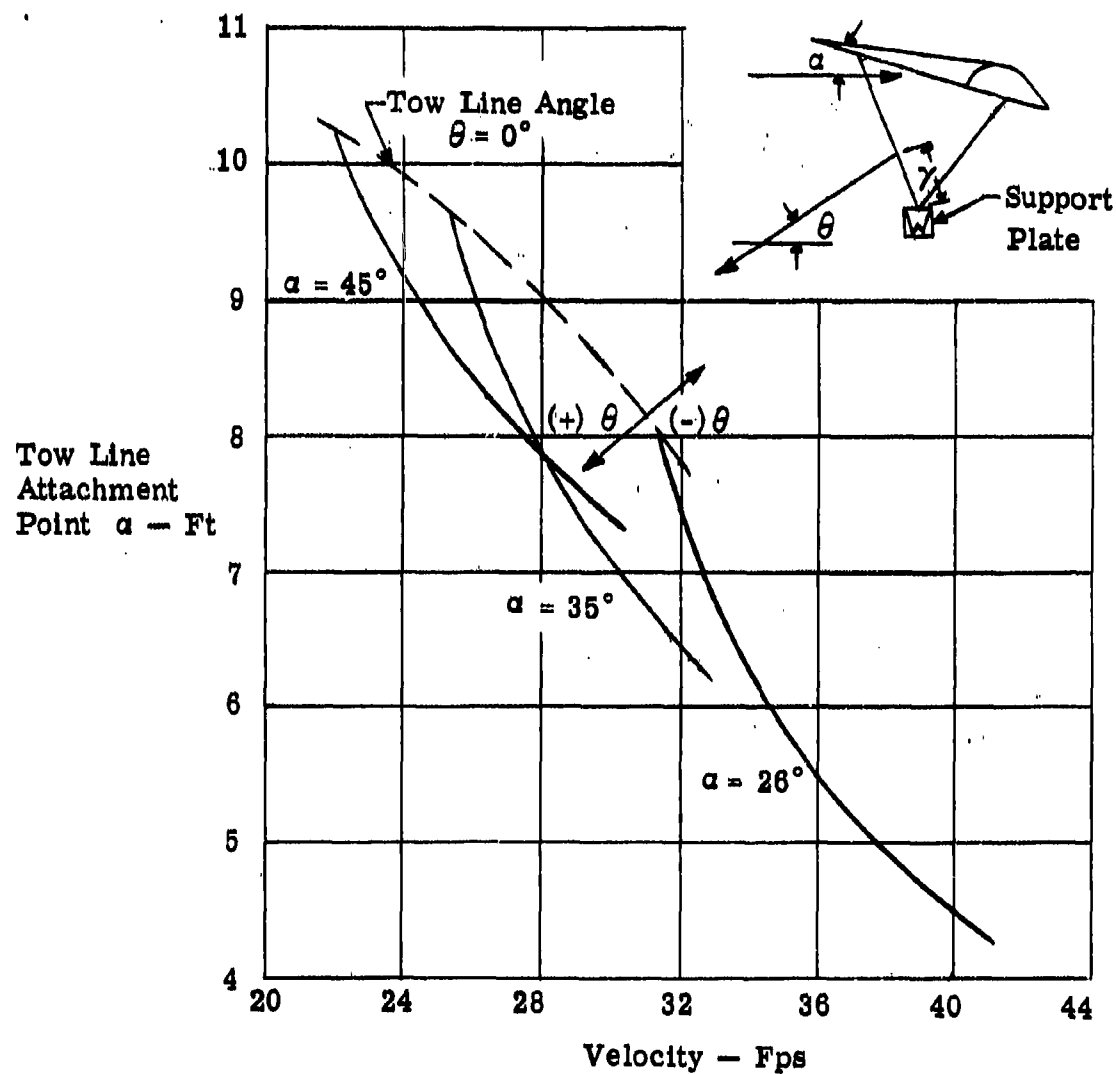


Figure 32. Towing Velocity Versus Tow Line Attachment Point For Stable Flight

Total Wt (W) = 175 lb
 Wing Sweep = 55°
 Wing Area = 285 ft^2

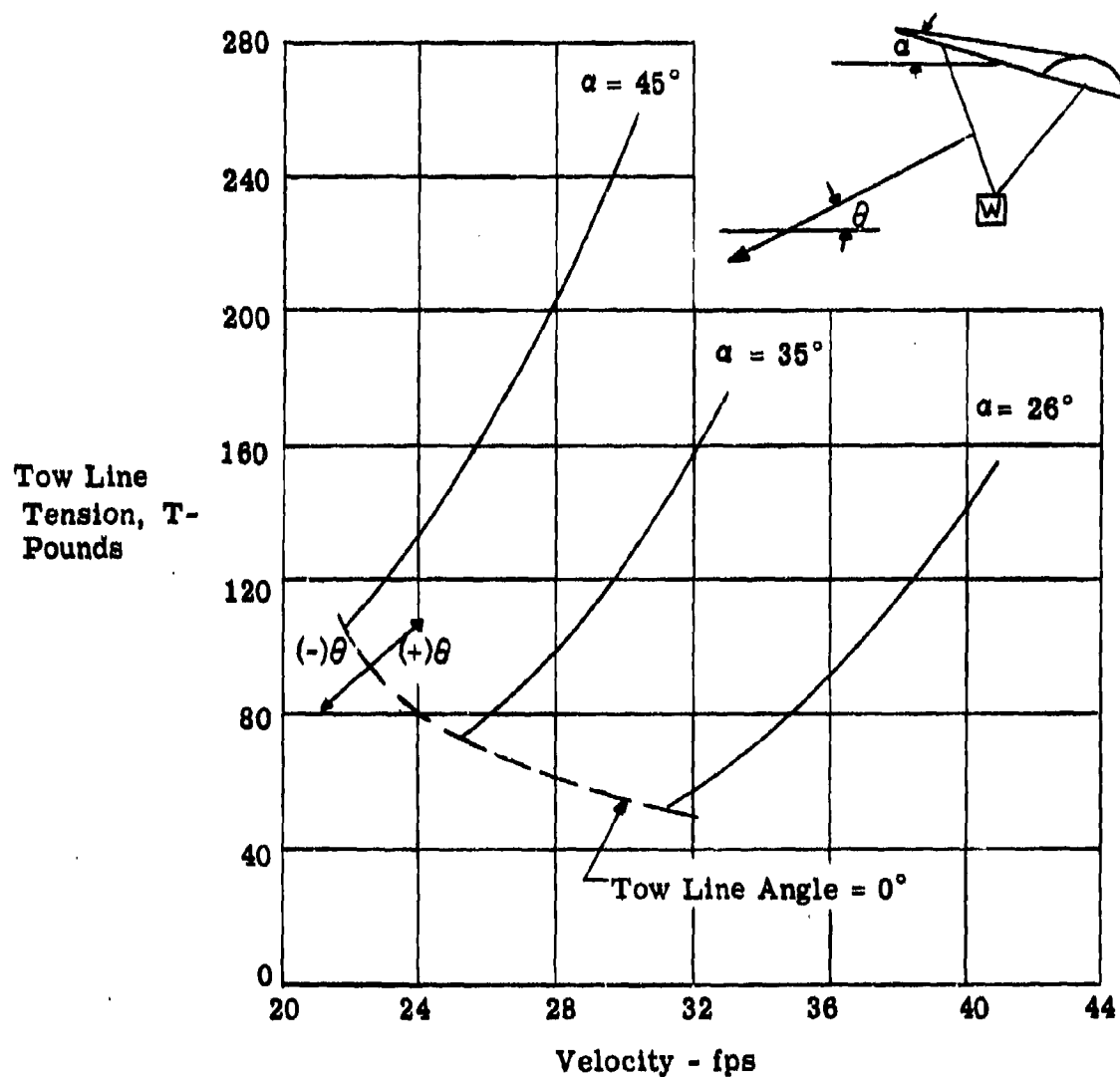


Figure 33 Towing Velocity Versus Tow Line Tension For Stable Flight

feet and the ground; the net effect is a modification of the pitching moment equation. Consequently, a similar variation of attachment point with velocity will be expected during this phase of the launch operation.

The conclusion reached was that a configuration adaptable to the portion of the launch prior to the lift-off of the man may not necessarily be feasible or even possible after lift-off if the required lift and stability plus a satisfactory tow-line angle are to be maintained.

3. Aerodynamic Stability and Control

Aerodynamic force and moment test data were obtained from NASA for paraglider configurations that were considered for the SRLD program. The data for a square planform with a deployed sweep angle of 55° were used to determine some of the pertinent stability and trim characteristics. The center-of-gravity position required for varying stability margins and trim-lift coefficients were calculated, and the results are presented in Figure 34. As illustrated, a straight-line variation of the vertical center-of-gravity (X/C) location exists which defines a given trimmed angle of attack or lift coefficient. Each line is in fact the line of action of the resultant aerodynamic force on the paraglider. For any particular vertical center of gravity location, aft movements of center of gravity will provide trim at progressively higher lift coefficients. However, the data show a boundary of center-of-gravity location at the higher lift coefficients within which the paraglider-SRLD system would be statically unstable. For this paraglider configuration, the unstable boundary occurs at lift coefficients of 0.77 to 0.85 depending upon the Z/C location. Note that increasing Z/C increases the margin of stability for a given trim-lift coefficient. Thus, during descent, the final flare maneuver just prior to touchdown (produced by moving the body center of gravity aft by rigging-lines movement) would be limited to lift coefficients of approximately 0.70 ($\alpha = 32^\circ$) to preserve a margin of stability for gusts or winds. For a selected Z/C location of 0.60, the amount of rigging line movement needed to change trim from $\alpha = 20^\circ$ to $\alpha = 32^\circ$ would be approximately $\Delta X = 0.11$, $C = 2.6$ feet. The effect on static stability of increasing the trim-lift coefficient (aft center-of-gravity movement) is shown in Figure 35. The results indicate that, except for a small amount of neutral stability near an angle of attach of 40° , the paraglider is statically stable up to very high (70°) angles of attack. We can conclude from this that any instability that might exist in the region of 40° would appear only as a transient condition during flare and would probably have an insignificant effect on the flare maneuver.

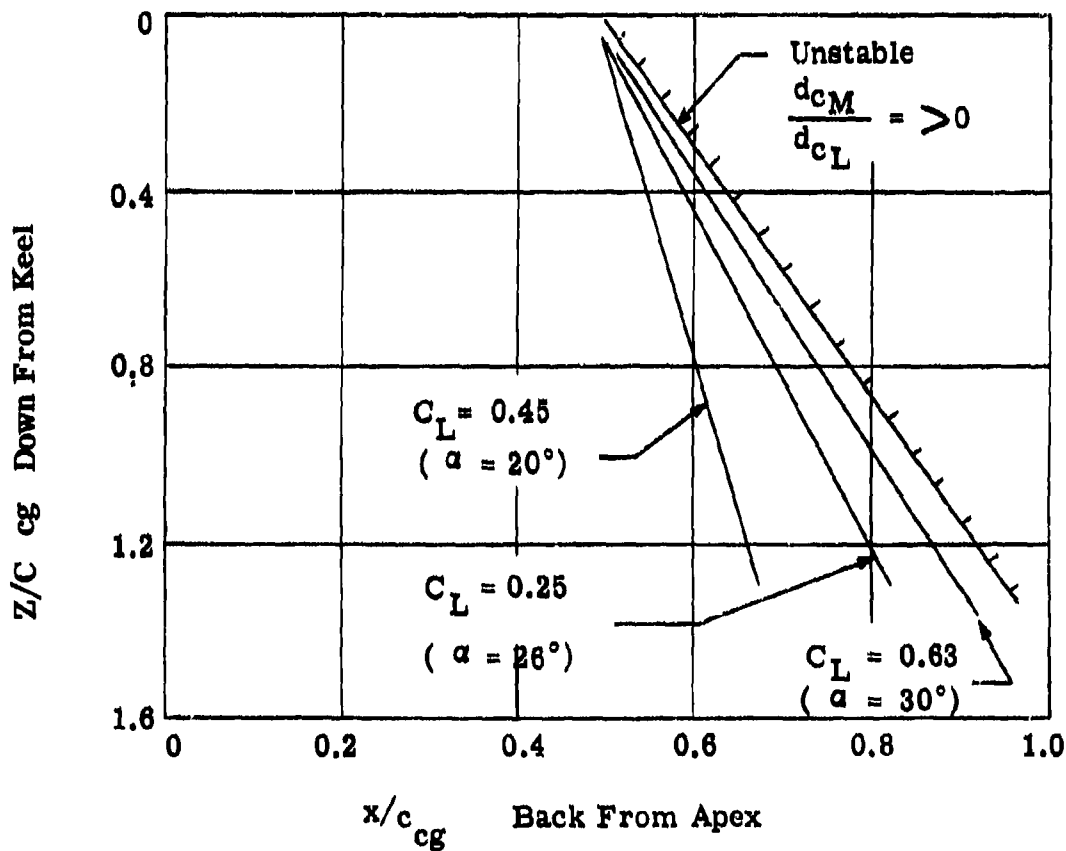


Figure 34. Center of Gravity Position for Varying Stability and Trim

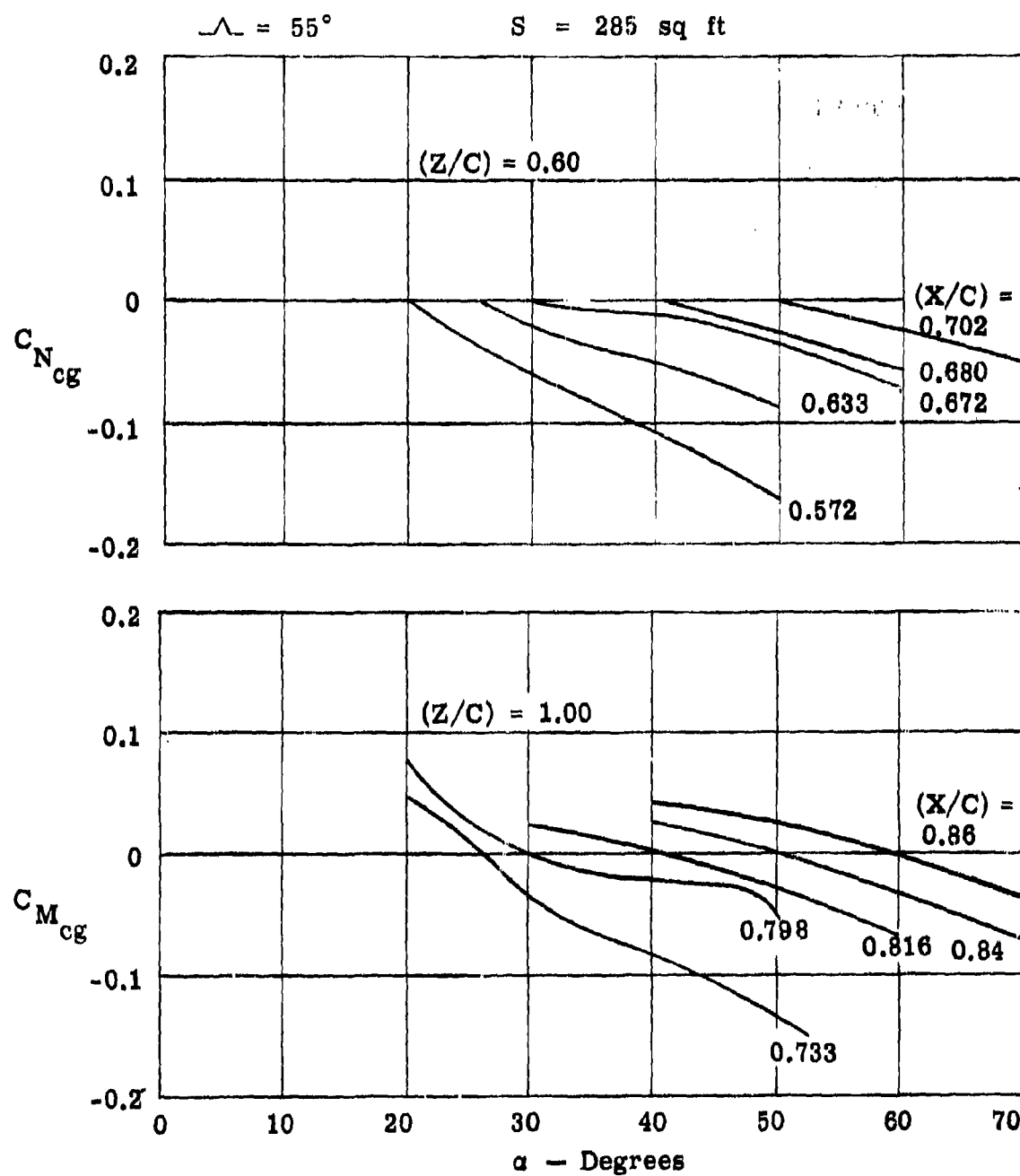


Figure 35. Static Stability

C. STRUCTURES

1. Discussion

The paraglider designed for this program was a flexible lifting surface vehicle designed to support a man suspended from it by shroud lines. The lifting portion of the glider is a canopy which is attached to a keel tube and two leading edge tubes. The shroud lines are also attached to these tubes.

The canopy carries the airload to the tubes by hoop tension. Therefore, the basic structure of the paraglider consists of the two leading edge tubes and the keel tubes. These tubes obtain their structural rigidity by means of internal pressurization.

The keel member supports approximately 50 percent of the vertical airloads and the leading edge members the remaining 50 percent. The leading edge members also carry lateral bending due to the lateral components of forces acting on the canopy and the shroud lines.

The configuration (geometric shape) is dictated by aerodynamic considerations. The structures effort is concentrated on:

- a. The location of the shroud lines in order to keep the bending moments imposed on the pressurized tubes to a minimum.
- b. A parametric study of the pressurized tubes in order to keep the weight of the paraglider at a minimum. The parameters considered are diameter, thickness and pressure.

2. Design Criteria

The following requirements were established for the structural design of the SRLD paraglider.

a. Safety factors

Yield	1.0 limit
Ultimate	1.5 limit

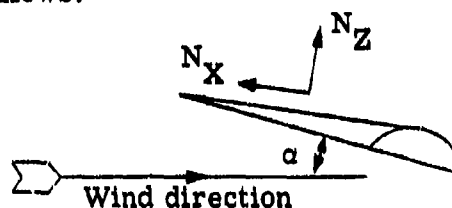
b. Failure resistance requirements

- Yield** - The loads shown herein are limit loads, unless otherwise stated. The paraglider structure shall not experience elastic or permanent structural deformations which impair its utility or integrity.
- Ultimate** - Ultimate loads are limit loads multiplied by an ultimate factor of safety of 1.5. The paraglider structure shall be capable of withstanding ultimate loads without rupture or collapse.

Loads

The weight of the operator and equipment will be 285 pounds.
The load factor combinations are as follows:

Cond.	N_Z	N_X
(1)	-0.36	-0.54
(2)	0	+0.81
(3)	-0.48	-0.20
(4)	+0.40	-0.27



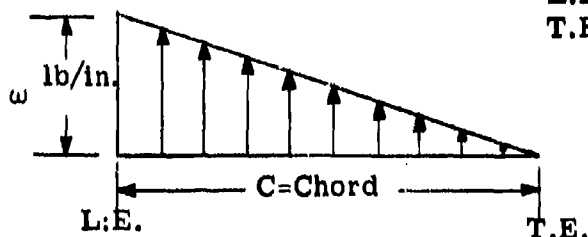
α = Angle of attack

Accelerations are positive
in direction shown.

N_Z & N_X are the
load factors
(accelerations)

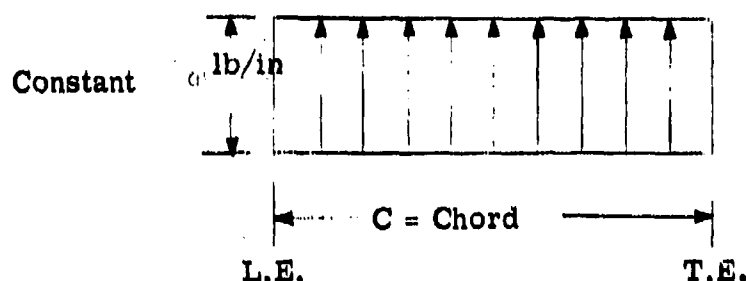
The chordwise pressure distributions have been taken as
follows:

For low angles of attack ($\alpha = 20$ degrees)



L.E. - leading edge
T.E. - tracking edge

For high angles of attack ($\alpha = 70$ degrees)



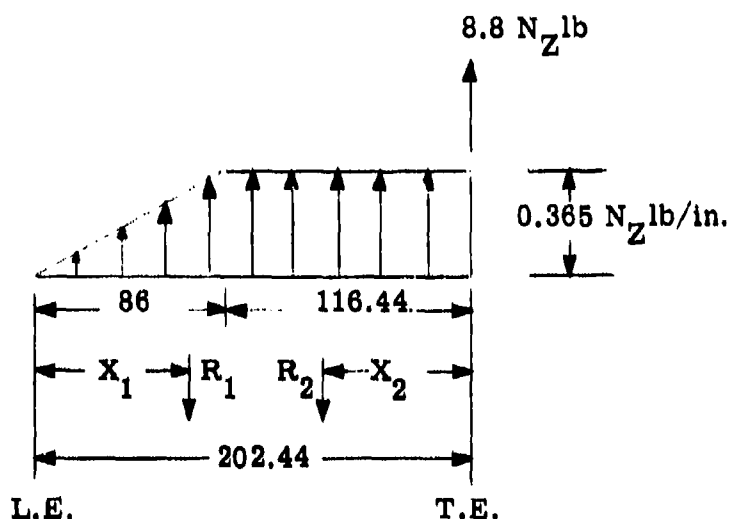
These distributions cover the full range of distributions as shown in NASA TN-D-983 dated November 1961.

These chordwise distributions result in the following loads on the leading edge and keel tubes.

Triangular Pressure Distribution

Leading Edge Tube

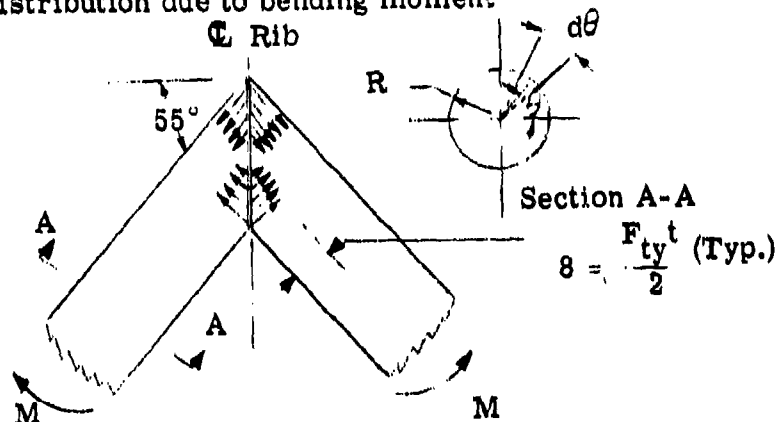
R_1 and R_2 = shroud line reactions



3. Analysis

Juncture of Leading Edge Tubes

Distribution due to bending moment



$$q = \frac{M}{2\pi r^2 t} \quad t = \frac{F_{ty}}{2} \quad t = \frac{pR}{t} \quad t = PR \text{ max.}$$

Axial Compressive Load on C Rib (P_c)

$$\begin{aligned} P_c &= 2 \int_0^{\pi/2} q R d\theta \sin 55^\circ = 2 \int_0^{\pi/2} pR (R d\theta) \sin 55^\circ \\ &= pR^2 \sin 55^\circ \int_0^{\pi/2} d\theta = pR^2 (0.8192) \left| \theta \right|_0^{\pi/2} \\ &= \frac{\pi (0.8192) pR^2}{2} = 1.288 pR^2 \end{aligned}$$

For the case of a 0.015 inch thick Mylar tube with 5-inch radius and $p = 4.2$ psi,

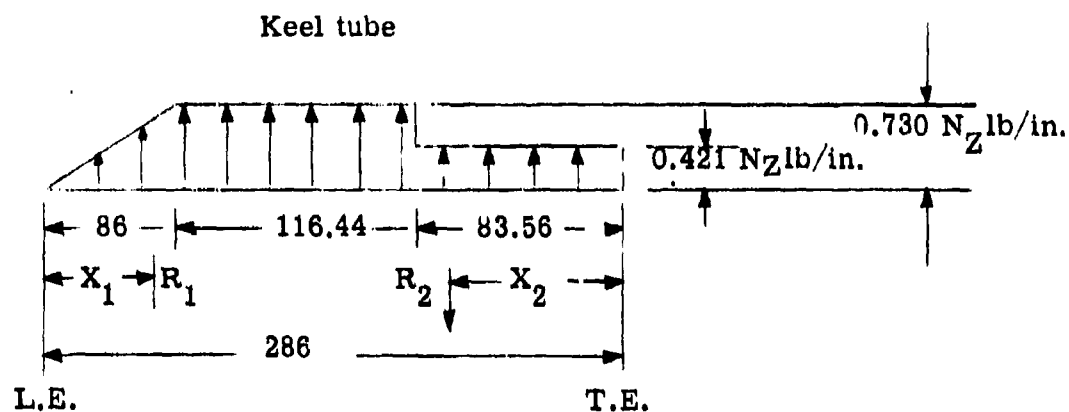
$$P_c = 1.288 (4.2) (5)^2 = 135 \text{ lb}$$

The horizontal components of the above (pR) loadings and all pressurization loadings are self-equilibrating.

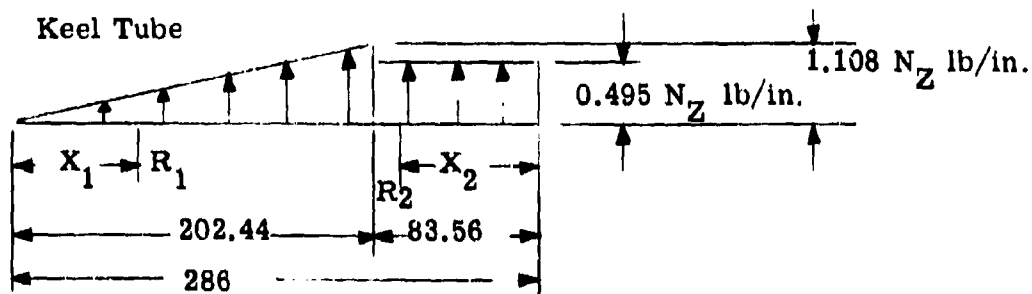
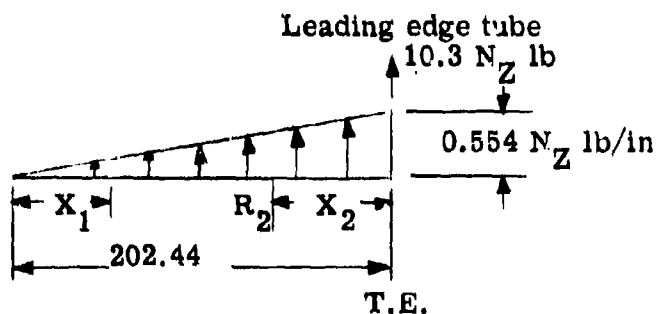
Loads

Triangular Pressure Distribution

R_1 and R_2 = shroud line reactions



Uniform Pressure Distribution



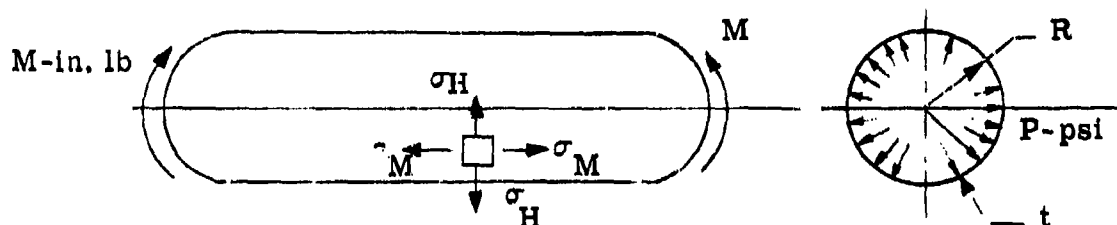
Bending Moments

A judicious placement of the shroud lines results in the following maximum bending moments on the tubes about a horizontal axis

Tube	X_1	X_2	$M_{\max.}$
Keel	84.5 in.	63.5 in.	900 Z in.-lb
L.E.	73 in.	21 in.	280 Z in.-lb

Tube - General

Since the tube material is not capable of sustaining any compressive forces, it must meet the following requirements:



Cross-Sectional Properties

$$I = \pi R^3 t$$

$$I/y = \pi R^2 t$$

Stresses

$$\sigma_H = \frac{\rho R}{t}$$

$$\sigma_M = \frac{\rho R}{2t} \pm \frac{M}{\pi R^2 t}$$

F_{ty} = material yield tensile allowable

Since, σ Mmax must = + f_{ty} and 0 in order to develop the maximum allowable bending allowable for the pressurized tube,

$$\frac{pR}{2t} = \frac{F_{ty}}{2} \quad \text{and} \quad \frac{M_i}{\pi R^2 t} = \frac{F_{ty}}{2}$$

Curves of the allowable bending moment for a Mylar tube versus radius, internal pressure, and tube thickness are shown in Figure 36. In Figure 37, bending moment allowables are shown for a leading edge tube tapered from a 5-inch radius to a 2.5-inch radius at $p = 4.2$ psi and $t = 0.015$ inch Mylar; and in Figure 38, allowable bending moment, required tube pressure, and weight are plotted versus tube diameter for 1- and 2-ply neoprene-impregnated nylon tubing (MIL-C-577E).

Conclusions

As a result of the analysis performed to date, it can be concluded that a flexible glider utilizing pressurized tubes as its primary structure is entirely feasible. Although the total loading spectrum has not been analyzed, it appears that tubes of the following material, diameter, and thickness would be capable of performing the structural task:

<u>Material</u>	<u>Thickness</u>	<u>Diameter</u>
Mylar	0.0043 in.	10 in.
Neoprene impregnated	1-ply	17 in.
Nylon (MIL-C-577E)	2-ply	12 in.
	3-ply	10 in.

Due to the pinholing tendencies of Mylar after folding several times, a decision was made to fabricate the first test pressurized para-glider structure from a 1.6-ounce nylon cloth coated to 4.5 ounces neoprene as per MIL-C-577D.

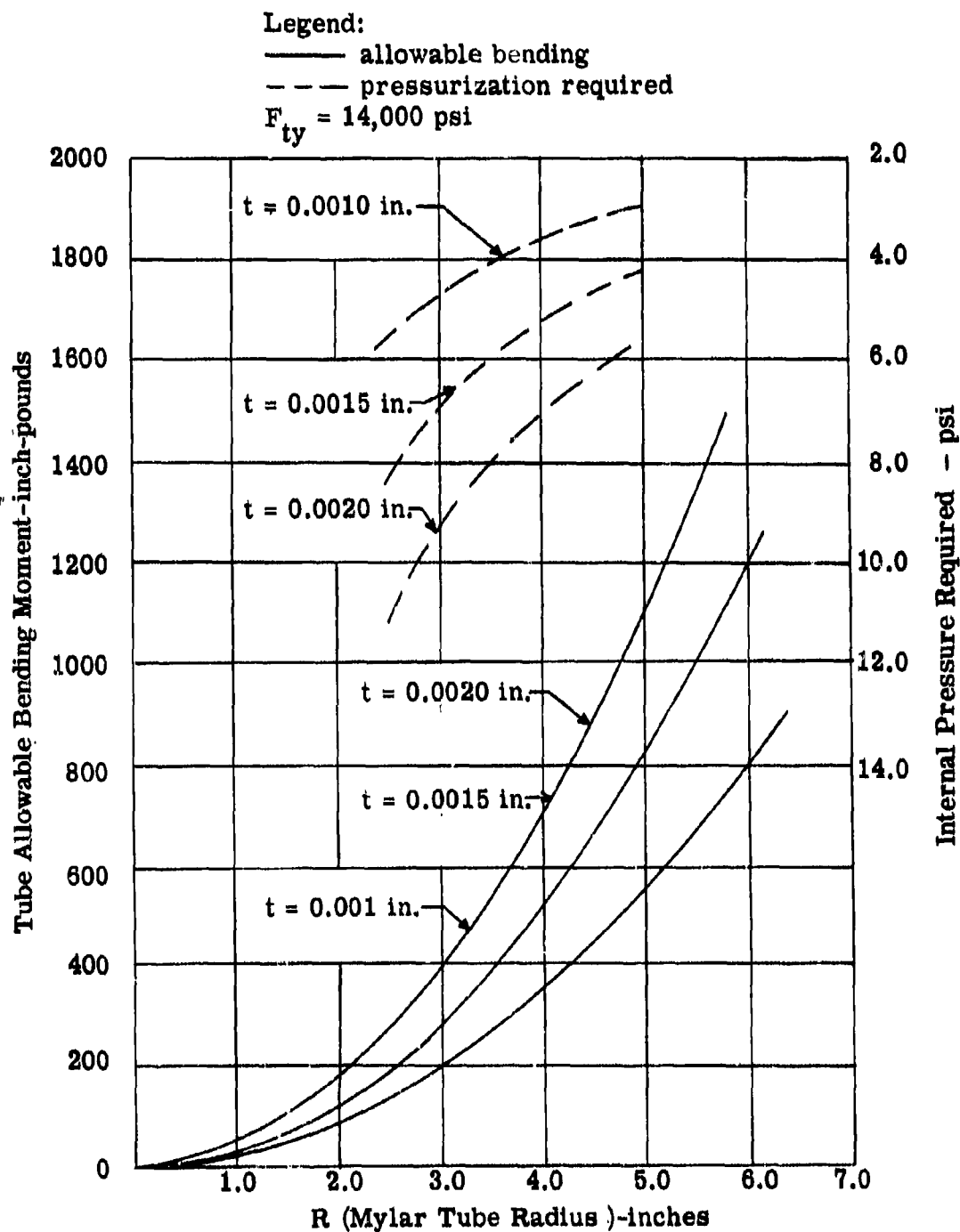


Figure 36. Mylar Allowable Bending Moment and Pressurization

$P = 4.2 \text{ psi}$
 $t = 0.015 \text{ in.}$
Material - Mylar
 $R = 5.0 \text{ in. at } 0 \text{ in. from L.E.}$
 $R = 2.5 \text{ in. at } 202.44 \text{ in. from L.E.}$

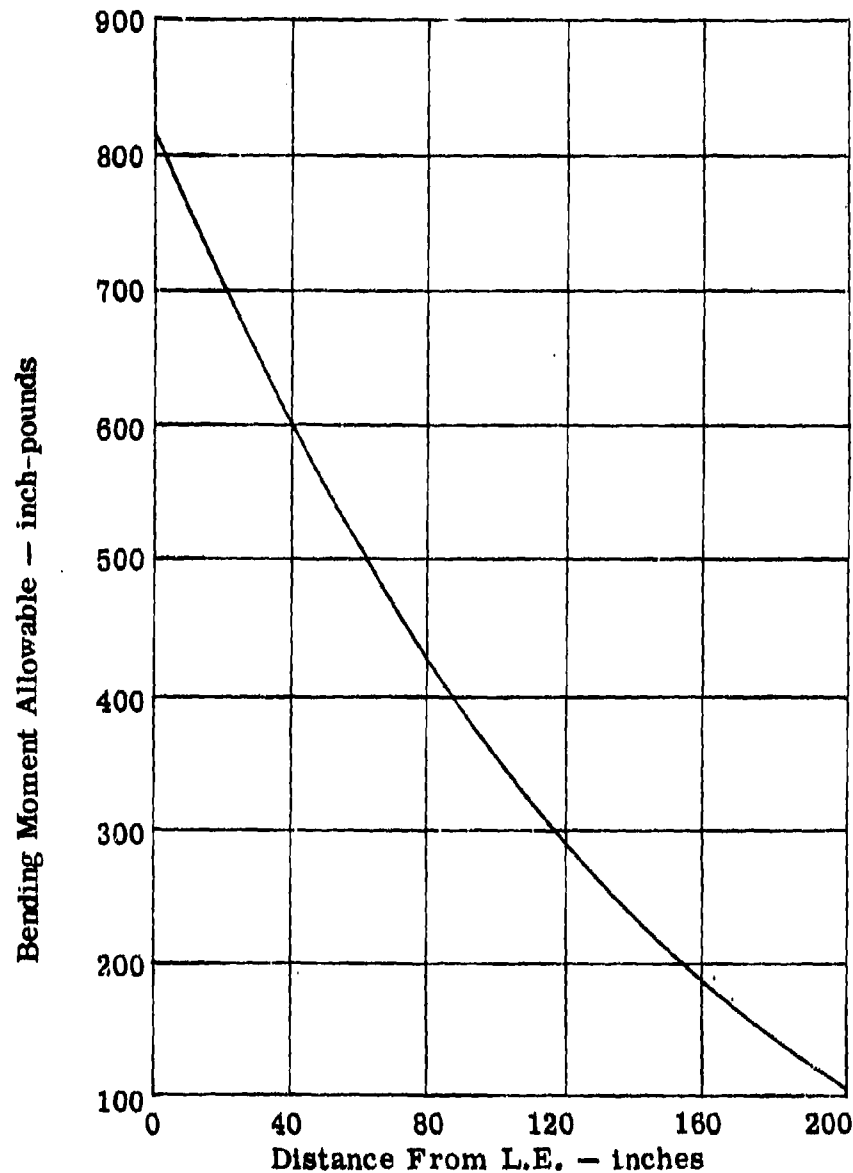


Figure 37. Bending Moment Allowable Tapered Leading Edge Tube

—— Type I Cloth, MIL-C-577E, Impregnated
4.5 ounce /sq yd

- - - - Type II Cloth, MIL-C-577E, Impregnated
6.0 ounce/sq yd

Allowable Tensile Loading - Ultimate

Type I 20 lb/in.

Type II 40 lb/in.

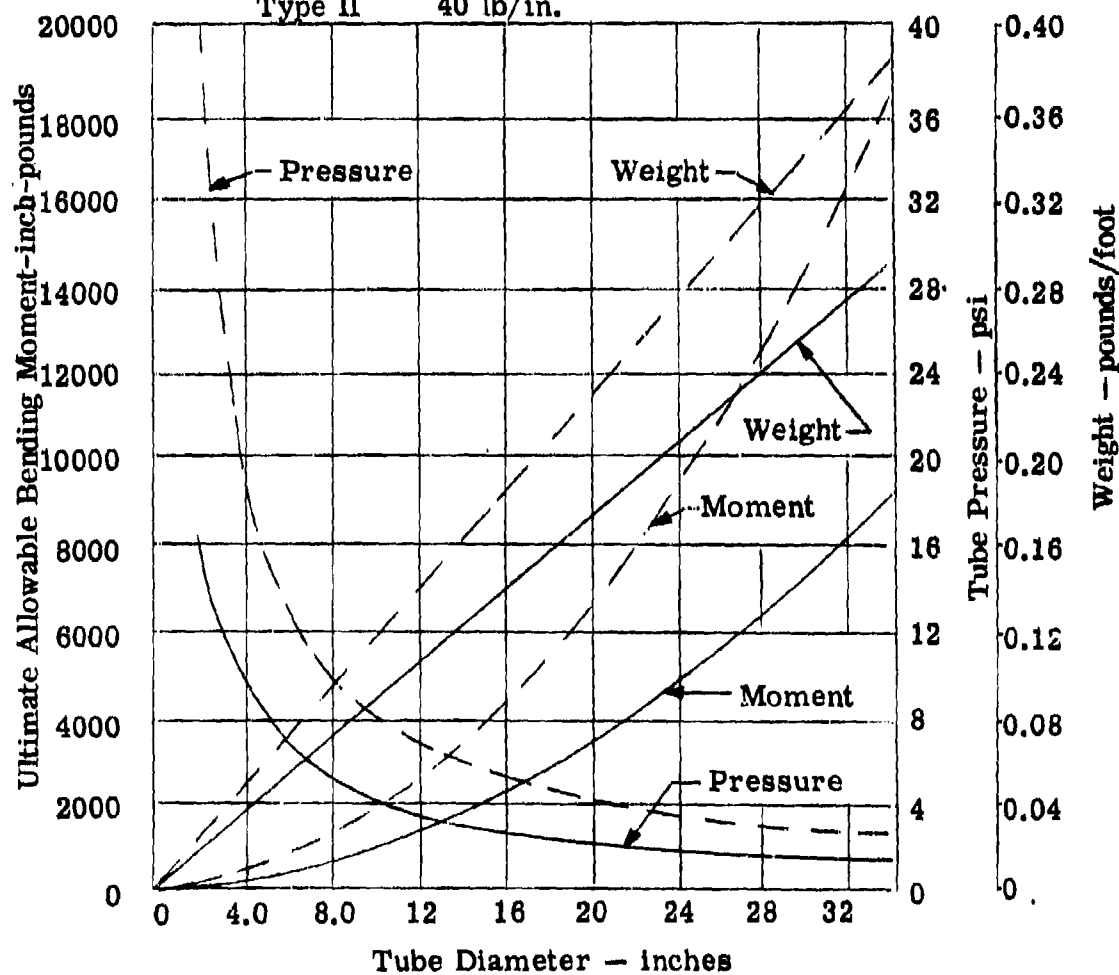
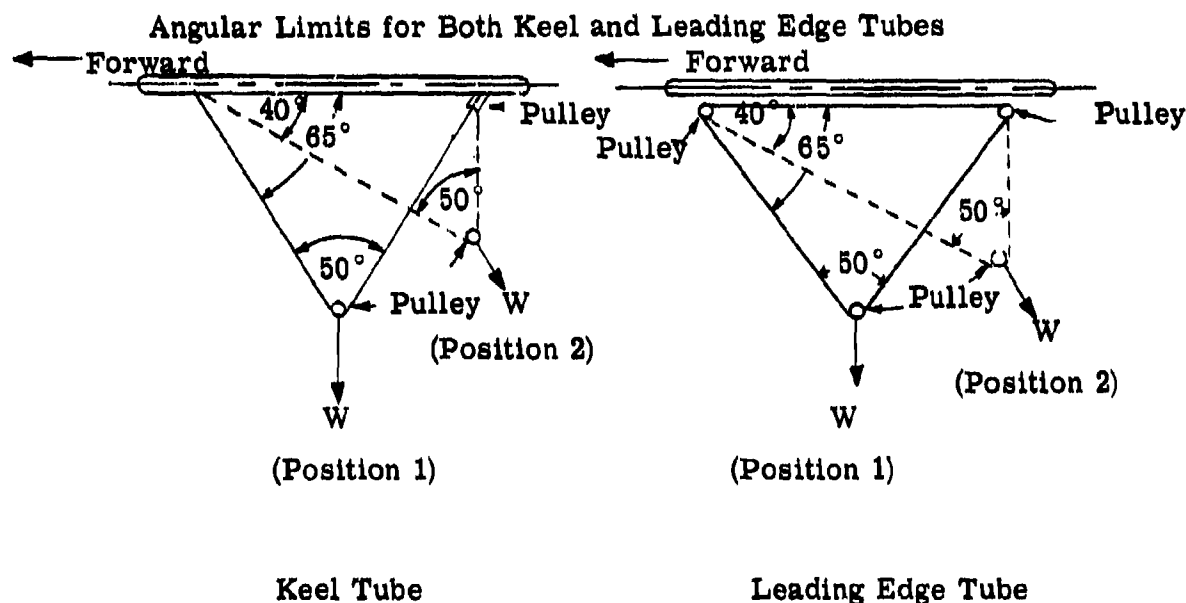


Figure 38. Structural Tube Selection

Eight 1-inch strips, four oriented in the warp direction and four oriented in the fill direction, were cut from the material and pulled in tension in the static test lab. Results of these tests are shown in Table 1.

Based on a minimum value of 37.0 pounds per inch ultimate or 24.6 pounds per inch limit curves (Figure 39) were plotted depicting the allowable limit bending moment of a tapered (12-inch diameter to 6-inch diameter) leading edge tube. Also shown in this figure are the 1g applied limit lateral bending moment and the lateral deflection under 1 g loads.

A check was also made of the compressive forces imposed on the leading edge and keel tubes by the angularity of the shroud lines. These computations, which show that the tubes are adequate for 1 g loads when pressurized to 4.1 psi, follow:

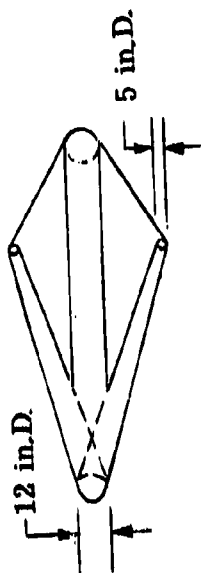


Since the shroud line is made of a single continuous line fastened at the front end of the keel tube, it has equal tension on all lines except for minor frictional forces at the pulleys. The line is single at each leading edge tube and doubled at the keel tube.

TABLE 1
TENSILE TEST

(1.6 oz. nylon cloth coated to 4.5 oz. with neoprene per MIL-C-577D)

Specimen No.	Cloth Orientation	Width (in.)	Thickness (in.)	Breaking Load (lb)	Breaking Stress (psi)	Elongation (%)
1	Fill	1	0.0075	44.0	5867	35
2	Fill	1	0.0072	38.4	5333	35
3	Fill	1	0.0073	37.0	5068	35
4	Fill	1	0.0070	42.8	6114	35
Avg.	Fill	1	0.0073	40.5	5550	35
5	Warp	1	0.0070	54.0	7714	17
6	Warp	1	0.0065	60.8	9354	17
7	Warp	1	0.0070	47.8	6828	17
8	Warp	1	0.0068	58.6	8618	17
Avg.	Warp	1	0.0068	55.3	8128	17



Tapered Leading Edge Tube

Mat'l - 1.6 oz nylon cloth coated to
4.5 oz with neoprene (MIL-C-577D)
Pressurization - 4.1 psi

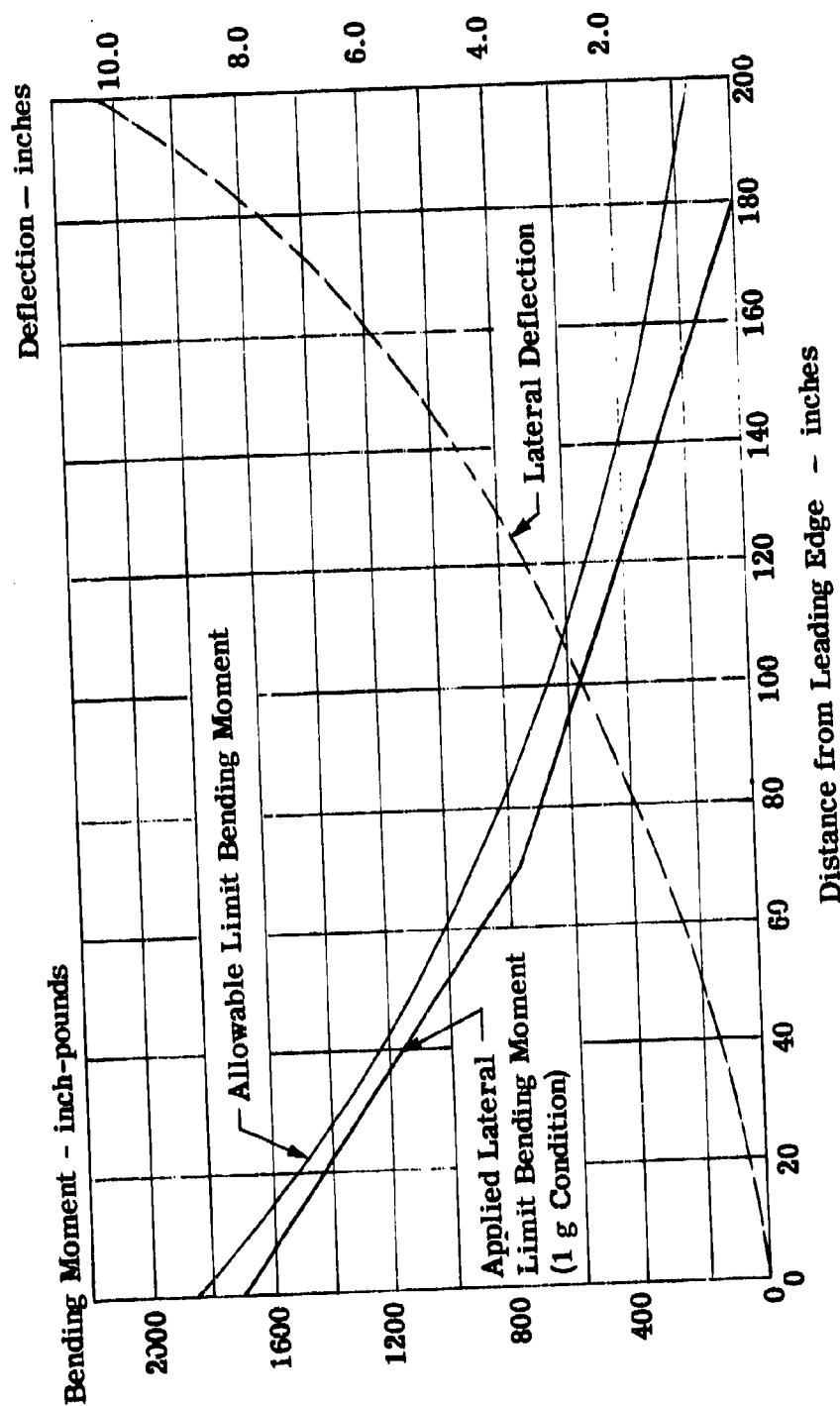
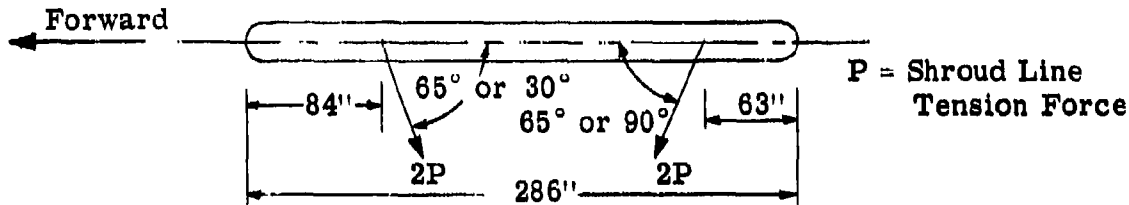


Figure 39. Structural Limit and Deflection Curves

W = 286 lb total

$$\text{Tension force in line} = \frac{286}{8 \cos \left(\frac{50}{2} \right)} = \frac{286}{(8) (0.9063)} = 39.4 \text{ lb}$$

Keel Tube (1 g condition)



$$2P = 2 (39.4) = 78.8 \text{ lb}$$

$$\begin{aligned} \text{Compressive load } P_c^* &= 78.8 \cos 65^\circ = 78.8 (0.4226) \\ &= 33.4 \text{ lb limit} \\ \text{or} &= 78.8 \cos 40^\circ = 78.8 (0.7660) \\ &= 60.5 \text{ lb limit} \end{aligned}$$

* In the first instance, the forward shroud component is reacted by the aft shroud component, while in the second case, the compressive force is reacted by the canopy as a constant load per inch along the tube. Thus,

$$\begin{aligned} P_{c_{\max}} &= 33.4 \text{ lb limit} \\ \text{or } 60.5 \left(\frac{286-84}{286} \right) &= 42.3 \text{ lb limit} \end{aligned}$$

$$M_{R_2} = 900 \text{ in-lb}$$

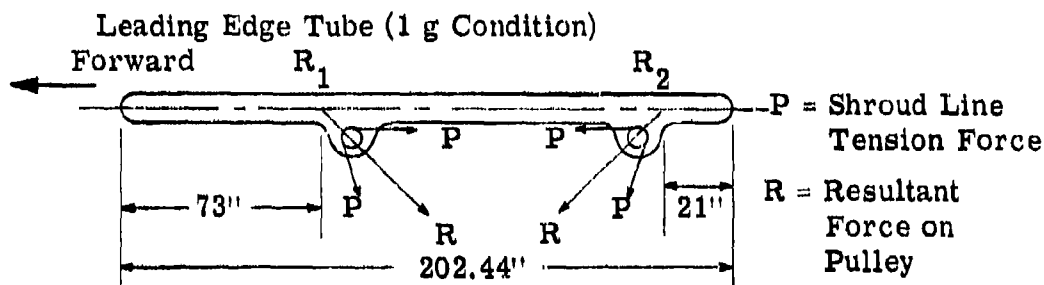
$$\begin{aligned} f_c &= \frac{P_c}{2 \pi R t} + \frac{M_R}{\pi R^2 t} = \frac{42.3}{2 \pi (6) t} + \frac{900}{\pi (6)^2 t} \\ &= \frac{1.12 + 7.86}{t} = \frac{8.98}{t} \text{ psi limit} \end{aligned}$$

However, since in the design of pressurized structures the collapsing bending moment is two times the buckling bending moment, we can rewrite the f_c stress equation to reflect this by multiplying the moment stress portion by the factor $\frac{1.5}{2.0} = 0.75$. Thus,

$$f_c = \frac{42.3}{2 \pi (6) t} + \frac{900 (0.75)}{\pi (6)^2 t} = \frac{(1.12 + 5.96)}{t} = \frac{7.08}{t} \text{ psi}$$

$$F_{co} = \frac{PR}{2t} = \frac{(4.1) (6)}{2t} = \frac{12.3}{t} \text{ psi limit}$$

$$M.S. = \frac{12.3}{7.08} - 1 = +0.74$$



The shroud line tension force (P) applies a resultant force (R) at each pulley which acts through the C_L of the leading edge tubes at points R_1 and R_2 . This resultant force has two components, one a shear force equal to $P \sin 65^\circ$ or $P \sin 45^\circ$ and the other a compressive force (P_c) equal to $P + P \cos 65^\circ$ or $P + P \cos 40^\circ$. These components of the resultant force are applied at the C_L of the leading edge tube.

$$P = 39.4 \text{ lb limit}$$

$$P_c^* = 39.4 + 39.4 \cos 65^\circ = 39.4 (1 + 0.4226) = 56.1 \text{ lb limit}$$

or $39.4 + 39.4 \cos 40^\circ = 39.4 (1 + 0.7660) = 69.6 \text{ lb limit}$

$$P_{c_{\max}} = 56.1 \text{ lb limit}$$

$$\text{or } 69.6 \frac{202.44 - 73}{202.44} = 44.5 \text{ lb limit}$$

$$M_R = 290 \text{ in.-lb limit.}$$

$$\text{At } R_2, R = 3.3 \text{ inches}$$

$$f_c = \frac{P_c}{2 \pi r T} + \frac{M_R (0.75)}{\pi R^2 t} = \frac{56.1}{2 \pi (3.3) t} + \frac{290 (0.75)}{\pi (3.3)^2 t}$$

$$= \frac{2.70 + 6.12}{t} = \frac{8.82}{t} \text{ psi limit}$$

$$F_{co} = \frac{PR}{2t} = \frac{(4.1) (3.3)}{(2) t} = \frac{6.8}{t} \text{ psi limit}$$

Since this results in a negative margin of safety, the final tube taper should be changed from a 12 to 6 taper to a 12 to 7 taper.

$$\text{Then, at } R_1, R = 3.76 \text{ inches}$$

$$f_c = \frac{56.1}{2 \pi (3.76) t} + \frac{290 (0.75)}{(\pi) (3.76)^2 t}$$

$$= \frac{2.37 + 4.89}{t} = \frac{7.26}{t} \text{ psi limit}$$

$$F_{co} = \frac{(4.1) (3.76)}{2t} = \frac{7.7}{t} \text{ psi limit}$$

$$\underline{\text{M.S.}} = \frac{7.7}{7.26} - 1 = \underline{+0.06}$$

Because of the many difficulties encountered during fabrication and test with the 1.6-ounce nylon cloth coated to 4.5 ounces with neoprene material, it was decided to use the heavier grade and stronger 3.0 ounce nylon cloth coated to 7.3 ounces with neoprene material. Tensile tests were run of both the parent material and the lap and butt splices of this material. The results of these tests are tabulated in Tables 2 and 3.

The lighter material seemed adequate, however, from test results shown in Table 2. However, tests were short time loadings which did not take into account the room temperature creep phenomenon of the nylon material, at high stress levels. This phenomenon is clearly evidenced by specimen no. 15 of Table 3.

Design improvements were incorporated in the nose section of the paraglider, and a new paraglider structure was fabricated from the new, heavier material. Cyclic pressure tests and leading edge lateral deflection tests were performed on the new structure. Results of these tests are shown in Table 4 and Figure 40.

A theoretical deflection, using simple beam theory, was calculated for the 4.0-psi pressure case with an applied load of 8 pounds, resulting in a theoretical tip deflection of 9.3 inches. This clearly shows that simple beam theory is not adequate for predicting tube deflections. The test deflection was $50/9.3 = 5.4$ times the theoretical. The tapered leading edge tube deflections of Figure 37 were recalculated and ratioed by the factor 5.4 and are presented as Figure 41. The allowable bending moment was also changed to reflect the leading edge tube ratio of 12- to 6-inch diameter of the paraglider structure instead of the 12- to 5-inch diameter ratio previously used.

TABLE 2
TENSILE TEST

(3.0-oz. nylon cloth coated to 7.3 oz. with neoprene (MIL-C-19002B)
No. 2079 TR)

Specimen No.	Cloth Orientation	Width (in.)	Thickness (in.)	Breaking Load (lb)	Breaking Stress (psi)	Elongation (%)
1	Fill	1	0.011	150	13,650	50
2	Fill	1	0.011	148	13,450	50
3	Fill	1	0.011	149	13,540	62
4	Fill	1	0.011	141	12,800	62
5	Fill	1	0.011	147	13,350	50
Avg.	Fill	1	0.011	147	13,350	55
1	Warp	1	0.011	171	15,550	75
2	Warp	1	0.011	175	15,900	75
3	Warp	1	0.011	179	16,270	68
4	Warp	1	0.011	164	14,900	62
5	Warp	1	0.011	163	14,800	75
Avg.	Warp	1	0.011	170	15,450	71

TABLE 3
JOINT TENSILE TEST

(3.0-oz. nylon cloth coated to 7.3 oz. with neoprene
(MIL-C-19002B) bonded with N-136 adhesive)

Specimen No.	Joint Type	Width (in.)	Material Thickness (in.)	Breaking Load (pounds)	Breaking Stress (psi)
1	Sanded Lap	1	0.011	120	10,900
2		1	0.011	135	12,280
3		1	0.011	108	9,810
4		1	0.011	131	11,900
5		1	0.011	131	11,900
6	Unsanded Lap	1	0.011	141	12,820
7		1	0.011	147	13,350
8		1	0.011	130	11,810
9		1	0.011	130	11,810
10		1	0.011	152	13,810
11	Butt not made to adhesive spec.	1	0.011	120	10,900
12		1	0.011	138	12,540
13		1	0.011	136	12,360
14		1	0.011	137	12,450
15		1	0.011	100	9,090
16	Butt made to adhesive spec.	1	0.011	130	11,810
17		1	0.011	137	12,540
18		1	0.011	133	11,080
19		1	0.011	137	12,540
20		1	0.011	140	12,720

- NOTES:**
- (1) Material overlap equals 1 inch in all cases.
 - (2) Specimens always failed in areas of single thicknesses of material.
 - (3) All specimens were loaded at an increasing rate until failure, except specimen no. 15. In this case, the 100-pound load was held for 6 minutes, at which time the specimen failed at the center of the butt.

TABLE 4

INTERNAL PRESSURIZATION CYCLE TEST

(paraglider made from 3.0 oz. nylon cloth coated to 7.3 oz. with neoprene)

Cycle No.	Internal Pressure psi	Pressure Applied at	Pressure Removed at	Elapsed Time Minutes
4	3-1/4	9:00 A.M.	9:05 A.M.	5
5	3-1/4	9:10 A.M.	9:18 A.M.	8
6	3-1/4	9:25 A.M.	9:37 A.M.	12
7	3-1/2	9:45 A.M.	10:00 A.M.	15
8	3-3/4	10:08 A.M.	10:23 A.M.	15
9*	3-3/4	10:35 A.M.	10:55*A.M.	20
9*	4	10:55*A.M.	11:30 A.M.	35
10	4	11:35 A.M.	1:30 P.M.	115

Date: 4/6/62

Witnessed By: H. Keefe and P. Kedzierski - Bell Aerosystems Company

* During cycle no. 9, the pressure was increased from 3-3/4 to 4 at 10:55 without reducing the pressure to zero as in the case of the other cycles.

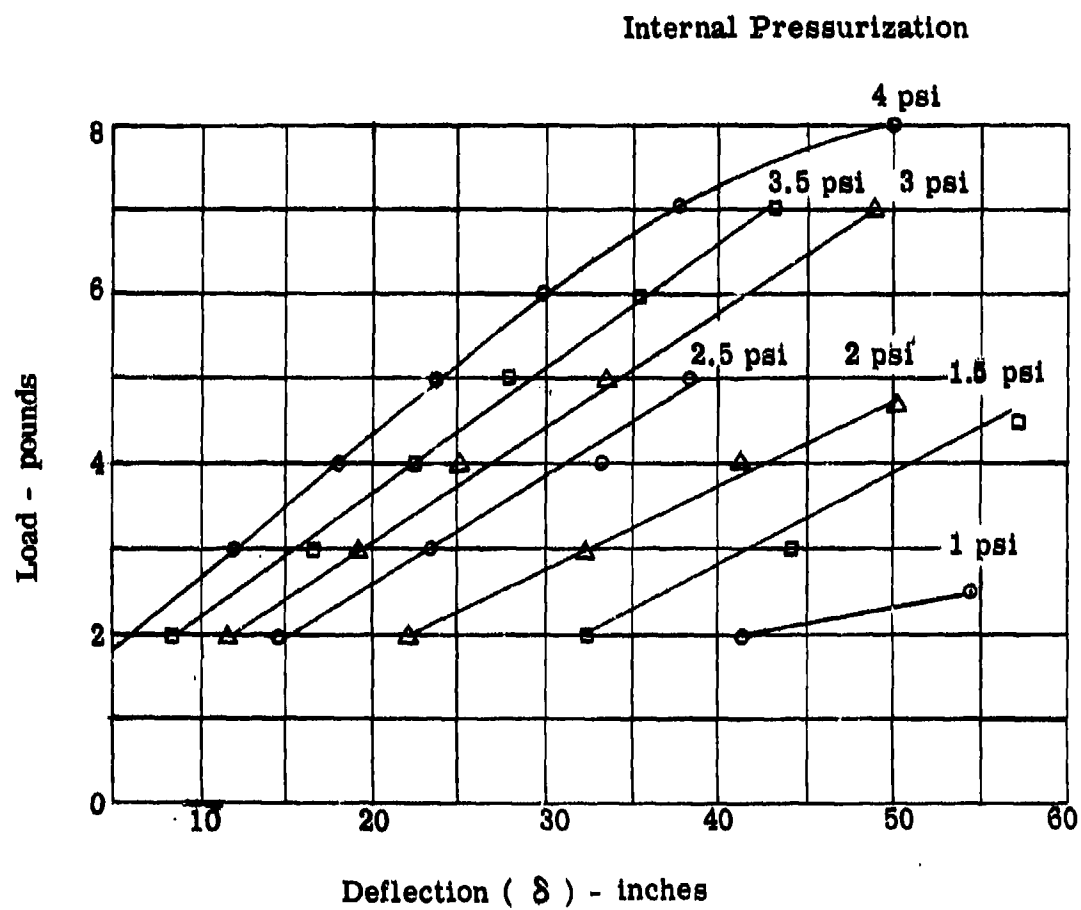


Figure 40. Load Versus Deflection Curves

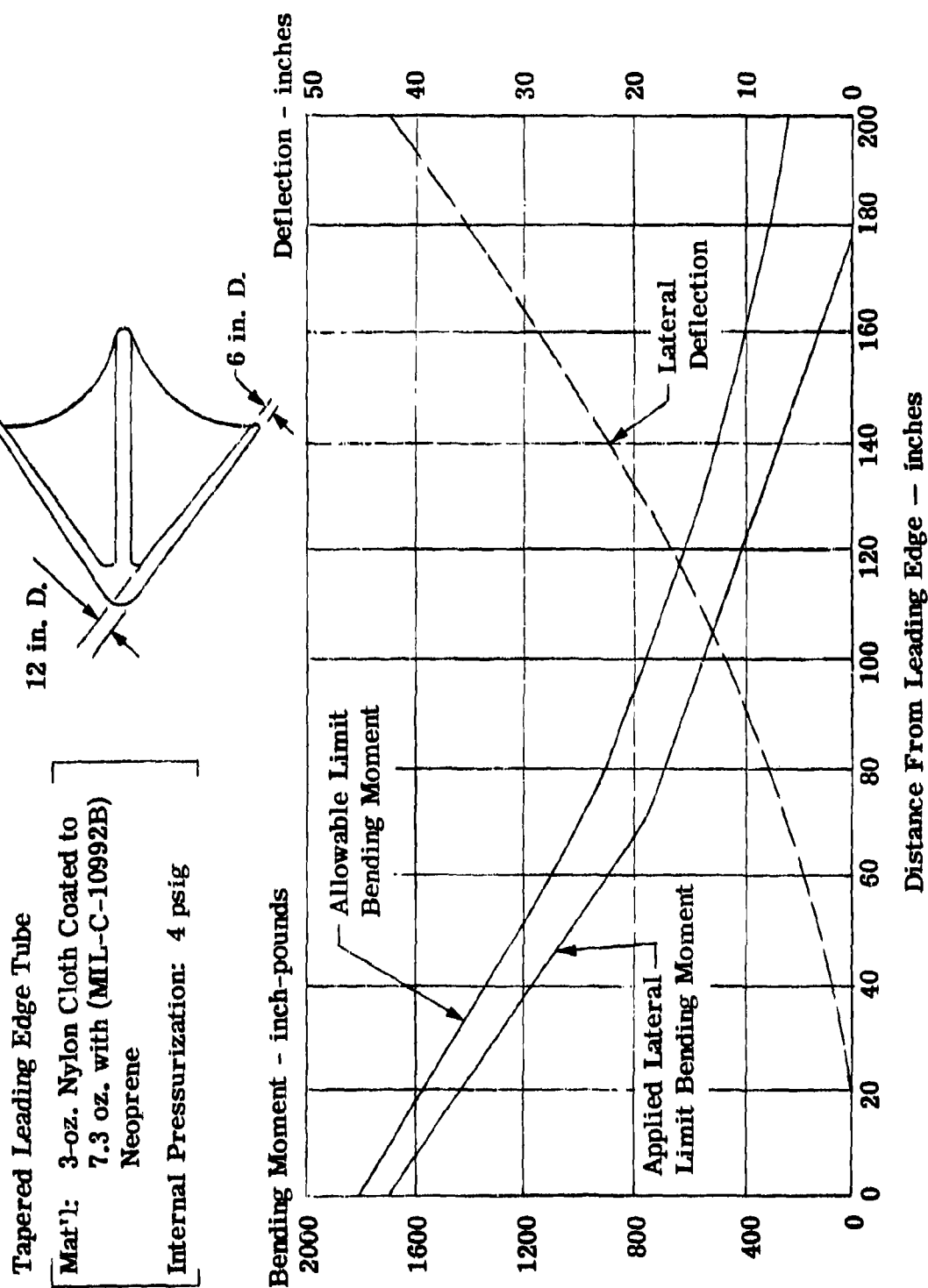


Figure 41. Structural Limit and Deflection Curves

III. SRLD STABILITY AND CONTROL

A. SUMMARY

The stability and control studies carried out during this phase of SRLD development centered about (1) yaw control studies and (2) improving the system dynamics represented on an analog computer by including more degrees of freedom on the mathematical model. The yaw control studies showed no significant effects of control power or gradient. However, the tendency to actuate the left-hand yaw control along with the right-hand throttle movements appeared. This tendency was detrimental to performing analog flights until the operator's skill improved and he learned to coordinate left- and right-hand control movements properly.

Satisfactory six-degree-of-freedom flight simulation depends on the proper display of pertinent parameters to the operator. Such a display was not available. Trial and error methods led to displays which could be used for studies limited to altitude heading and one-space coordinate; namely, forward translation. These translatory flights were performed easily on the simulator when the operator did not apply pitching moments; addition of pitching moment control made flights more difficult. The two-segment mathematical model lacks the feature of allowing the operator some control over the relative angular displacement of the upper and lower body, which is contrary to the real situation.

The six-degree-of-freedom system dynamics were later instrumental on the computer in anticipation of correlating flight test data along with theoretical studies. These data, scheduled to be obtained from another contract, were never realized due to difficulties preventing the development of a satisfactory data acquisition system necessitating contract termination. Figure 42 shows the telemetering transmitting instrumentation that was installed on the SRLD. Figure 43 shows the receiving instrumentation installed in the trailer that was originally acquired from the Navy for the paraglider program.

B. INTRODUCTION

Active stability and control studies had been pursued long before the first successful free flight was performed. Many of the analyses were simple and were directed toward problem areas which appeared in early tethered flights with a nitrogen gas powered rig. With the nitrogen gas rig, lateral translation and rolling motions were oscillatory and, for the most

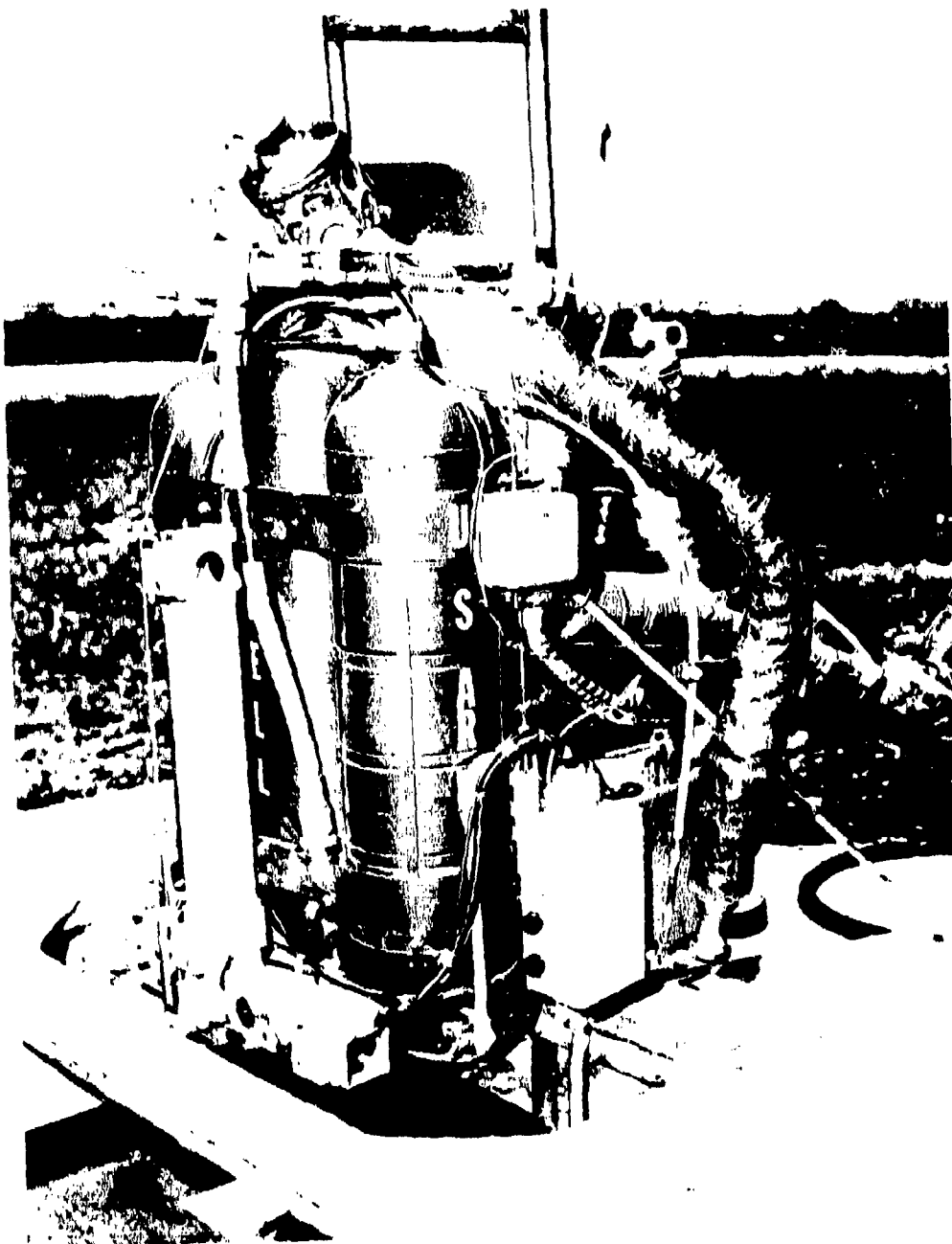


Figure 42. SRLD with Mounted Instrumentation

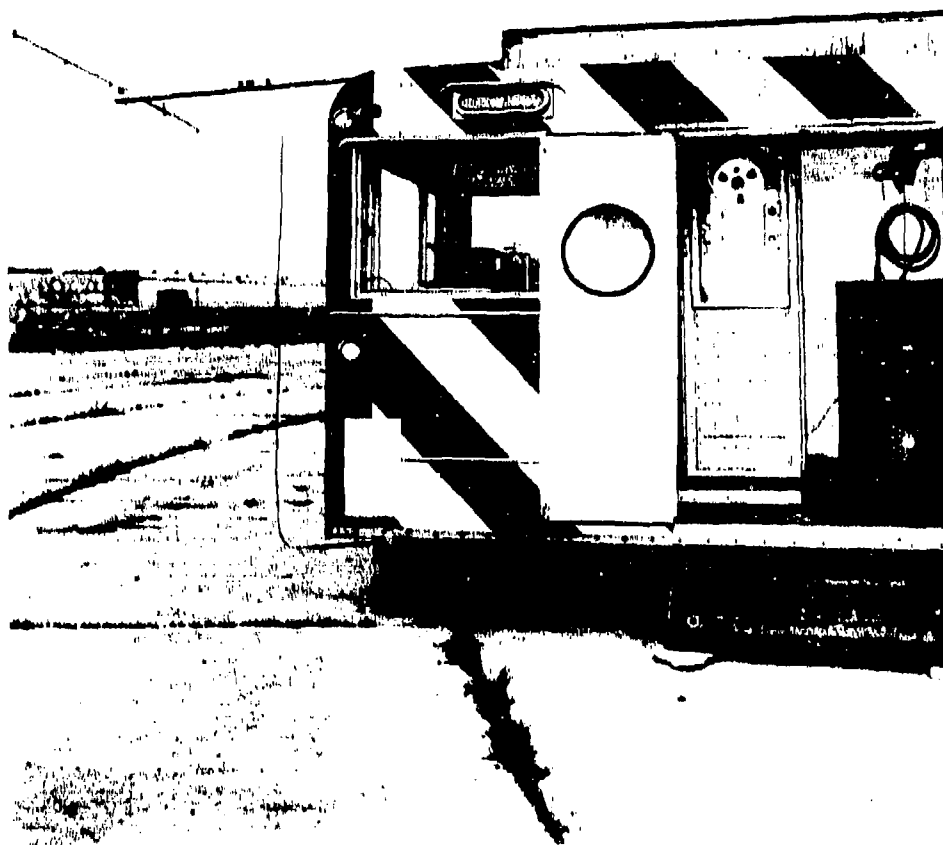


Figure 43. Telemetering Equipment Installed in Trailer

part, difficult to control. When the hydrogen peroxide propulsion system became operative, early tethered flights were difficult because of thrust modulation problems. These problems were investigated using a human operator to control system dynamics which were mechanized on an analog computer. References 2, 3, and 4 document the analyses and tests and present the pertinent results acquired.

During this phase of SRLD development, stability and control effort was continued; the emphasis in these studies was on more sophistication in the man-machine system concept, utilizing a human operator in conjunction with an analog computer. The stability and control work accomplished for the paraglider auxiliary lift device is in Section II of this report.

C. METHOD OF ANALYSIS

A block diagram of the man-machine combination is shown in Figure 44. System dynamics are represented on an analog computer. The operator controls the system by observing a display which provides the necessary cues indicative of position and attitude with respect to the earth.

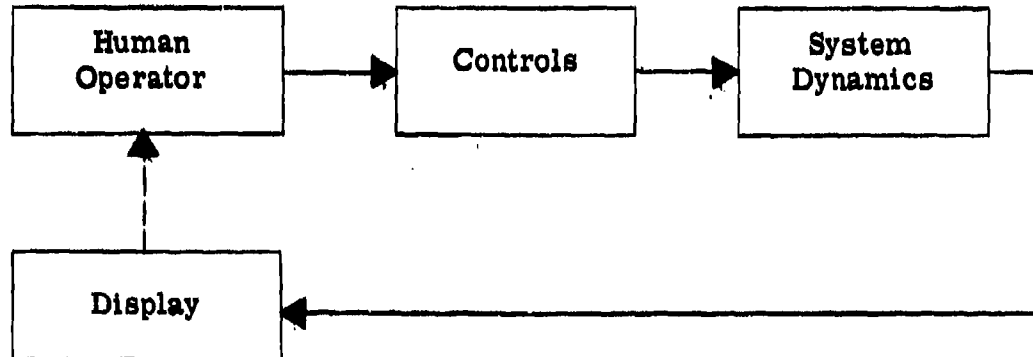


Figure 44. Block Diagram of Man-Machine Combination

The mathematical model used to represent the SRLD is shown in Figure 45. This model consists of a two-segment body, the upper portion representing the man's torso, the attached gimbaled nozzle hardware,

and the remaining propulsion components; and the lower portion representing his legs. This model is essentially the same as used in previous studies except that the defining equations of motion are provided for six-degree-of-freedom motion. The bodies are attached at a point corresponding to the hip joint. Each was assumed to pitch and roll about the hip pivot independent of the other, but any yawing motion was common to both. The equations of motion were written separately for each segment with respect to moving-body-fixed axes whose origin was at the pivot. These reference axes are shown in Figure 45.

The exact equations of motion were simplified considerably by assuming small perturbations and neglecting most perturbation products. The equations mechanized on the computer are:

Force Equations:

$$\begin{aligned}\ddot{X}_O &= \frac{1}{m_{tot}} \left\{ \cos \psi \left[(\theta_1 + \theta_c) T - m_1 z_1 (\dot{q}_1 + r p_1) - m_2 z_2 (\dot{q}_2 + r p_2) \right] \right. \\ &\quad \left. + \sin \psi \left[\phi_1 T - m_1 z_1 (\dot{p}_1 - r q_1) - m_2 z_2 (\dot{p}_2 - r q_2) \right] \right\} \\ \ddot{Y}_O &= \frac{1}{m_{tot}} \left\{ \cos \psi \left[-\phi_1 T + m_1 z_1 (\dot{p}_1 - r q_1) + m_2 z_2 (\dot{p}_2 - r q_2) \right] \right. \\ &\quad \left. + \sin \psi \left[(\theta_1 + \theta_c) T - m_1 z_1 (\dot{q}_1 + r p_1) - m_2 z_2 (\dot{q}_2 + r p_2) \right] \right\} \\ \ddot{Z}_O &= \frac{T}{m_{tot}} - g\end{aligned}$$

Moment Equations:

Pitch:

$$\begin{aligned}\dot{q}_1 &= \frac{K_\theta (\theta_2 - \theta_1)}{m_1 k_{y1}^2} - \frac{z_1 (\theta_1 + \theta_c) T}{k_{y1}^2 m_{tot}} + \frac{m_2 z_1 z_2}{k_{y1}^2 m_{tot}} (\dot{q}_2 + r p_2) + \frac{z_1 g \theta_1}{k_{y1}^2} \\ &\quad + \frac{T(z_1 + \Delta z) \theta_c}{m_1 k_{y1}^2} - p_1 r \left[1 - \left(\frac{k_{z1}}{k_{y1}} \right)^2 \right] + \frac{m_1 z_1^2}{k_{y1}^2 m_{tot}} (\dot{q}_1 + r p_1)\end{aligned}$$

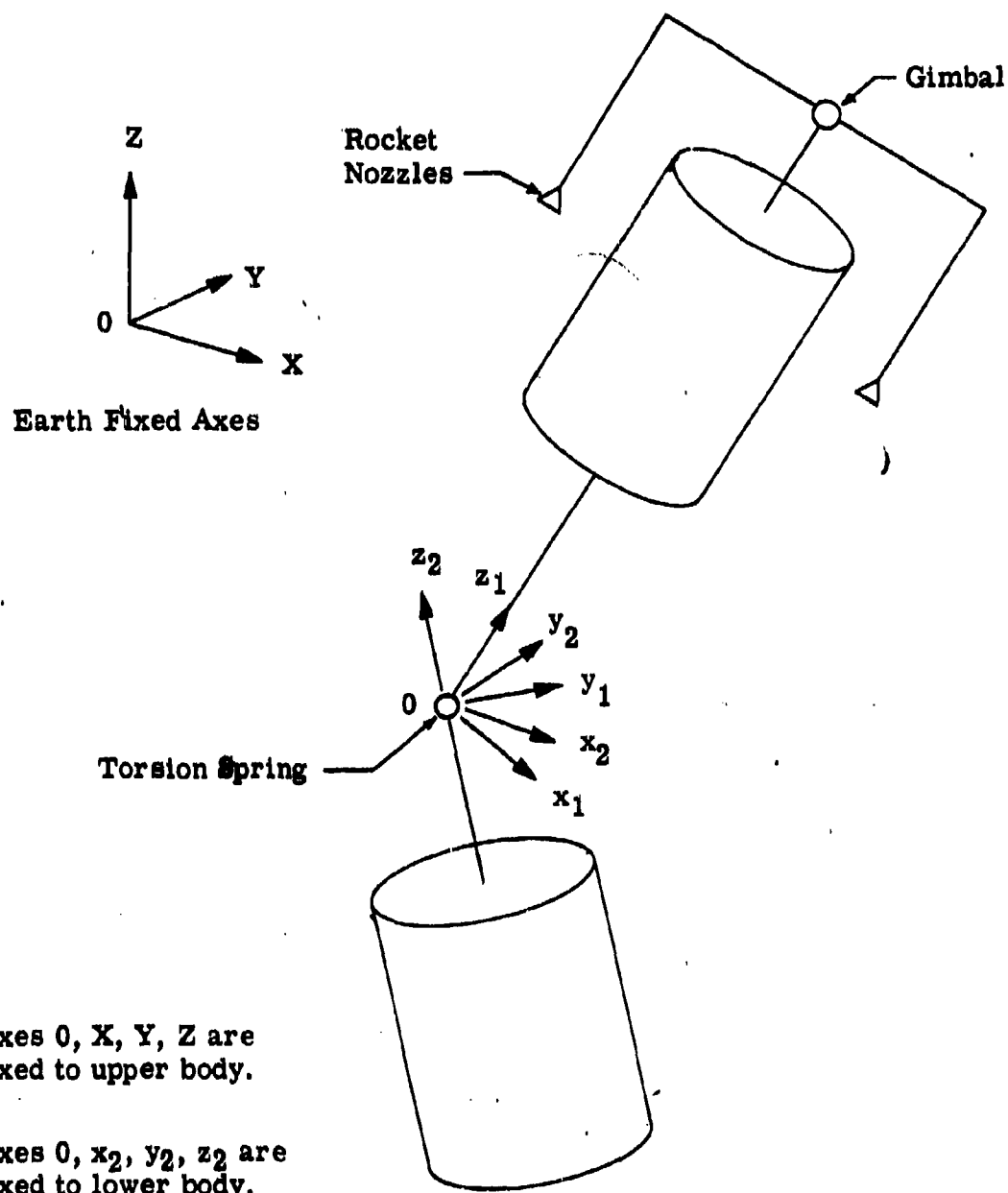


Figure 45. Mathematical Model of Two-Segment Body

$$\ddot{q}_2 = - \frac{K_\theta (\theta_2 - \theta_1)}{m_2 k_{y2}^2} + \frac{z_2}{m_{tot} k_{y2}^2} \left[\theta_1^T + m_1 z_1 (\dot{q}_1 + r p_1) + m_2 z_2 (\dot{q}_2 + r p_2) \right] \\ - p_2^r \left[1 - \left(\frac{k_{z2}}{k_{y2}} \right)^2 \right] - \frac{z_2^T \theta_c}{k_{y2}^2 m_{tot}} + \frac{3_2 g \theta_2}{k_{y2}^2}$$

Yaw

$$\ddot{\psi} = \frac{T_l}{I_{z_{tot}}} \delta \eta$$

The roll moment equations are similar in form to the pitch equations since the mathematical model is symmetrical with respect to the pitch and roll modes. The effect of variable mass due to propellant consumption was included, but center-of-gravity change due to propellant consumption was ignored.

D. DISPLAYS

A display is a very important part of a study involving a human operator since it provides, or should provide, the necessary cues with which he can control the system dynamics represented on the computer. An x-y plotter and an oscilloscope were used initially to form a display.

For vertical flight or hovering studies, only an oscilloscope was used. A moving pip represented altitude and heading as shown in Figure 46.

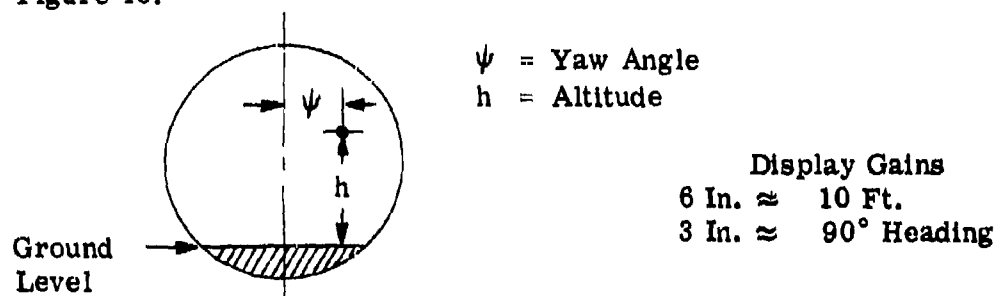


Figure 46. Oscilloscope Yaw-Altitude Display

When the x-y plotter was used with the oscilloscope, a satisfactory display was not immediately achieved. A trial and error procedure was followed until a usable display evolved. Figure 47 shows the first display schematic used for combined longitudinal and yaw flights. Two oscilloscopes and an x-y plotter were used. One oscilloscope showed the same parameters as in Figure 48, while the other presented upper-body pitch attitude. The x-y plotter presented the earth x-y coordinates. Analog flights could not be made using this display. It seemed that the task of coordinating control movements while observing and extracting cues from this display was too difficult.

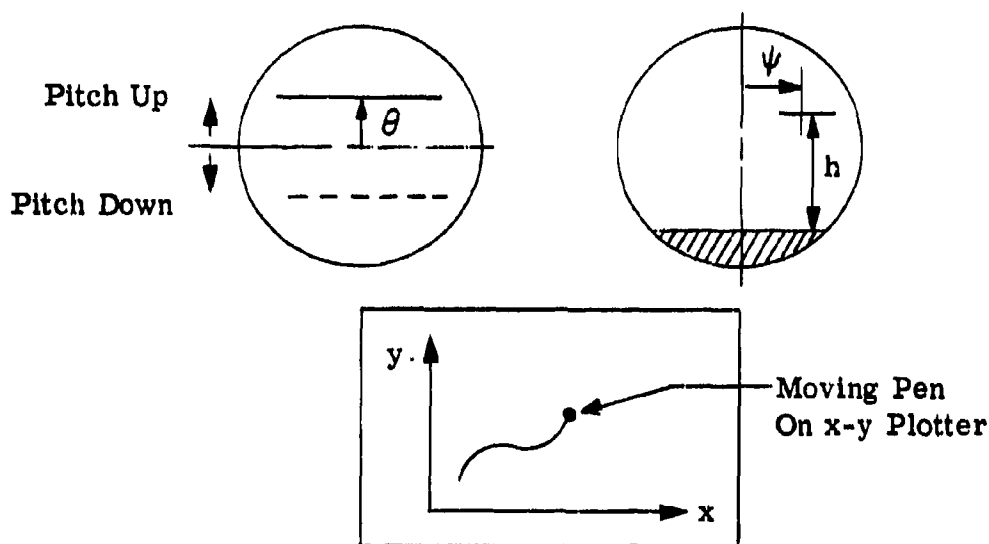


Figure 48. Oscilloscope and X-Y Plotter Display for Longitudinal and Yaw Flights

Figure 49 shows a display that proved to be satisfactory for translational flights in which pitch control was not used. An x-y plotter with two moving pens was employed. The lower pen showed altitude as a function of forward distance, and the upper pen showed yaw deviations as a function of forward distance.

When pitch control was added, an oscilloscope showing pitch attitude was used with the x-y plotter. Flights were slightly more difficult when the oscilloscope was added since the operator was presented with an additional display to monitor.

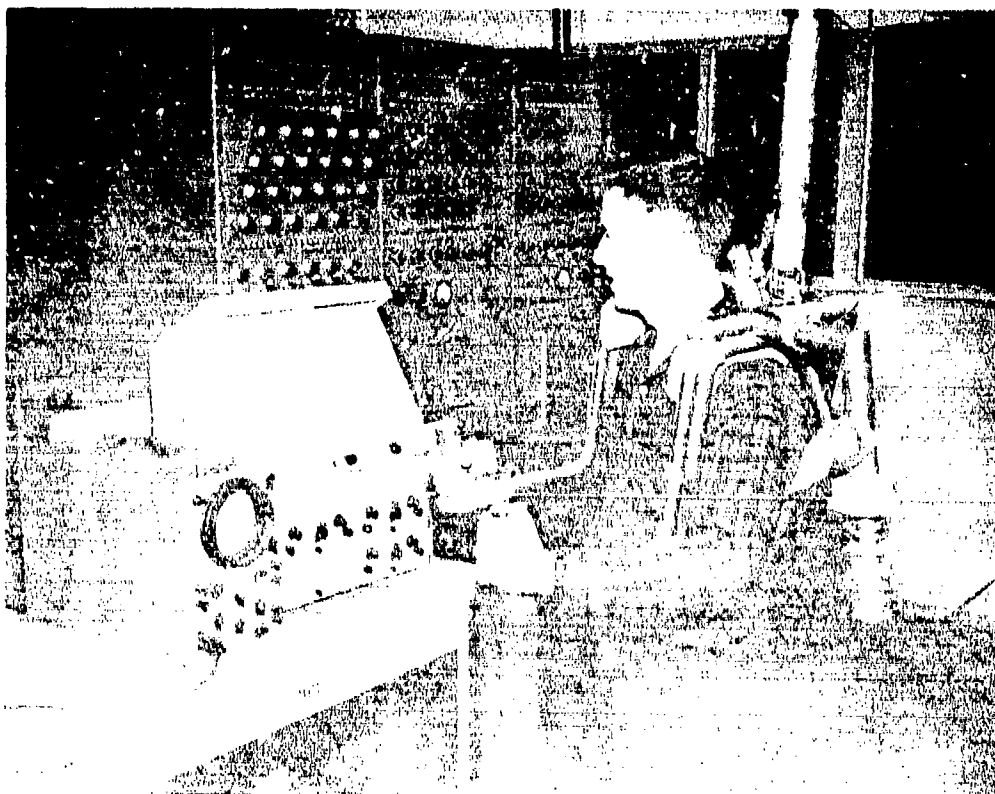


Figure 47. Simulated Analog Control Rig Mockup

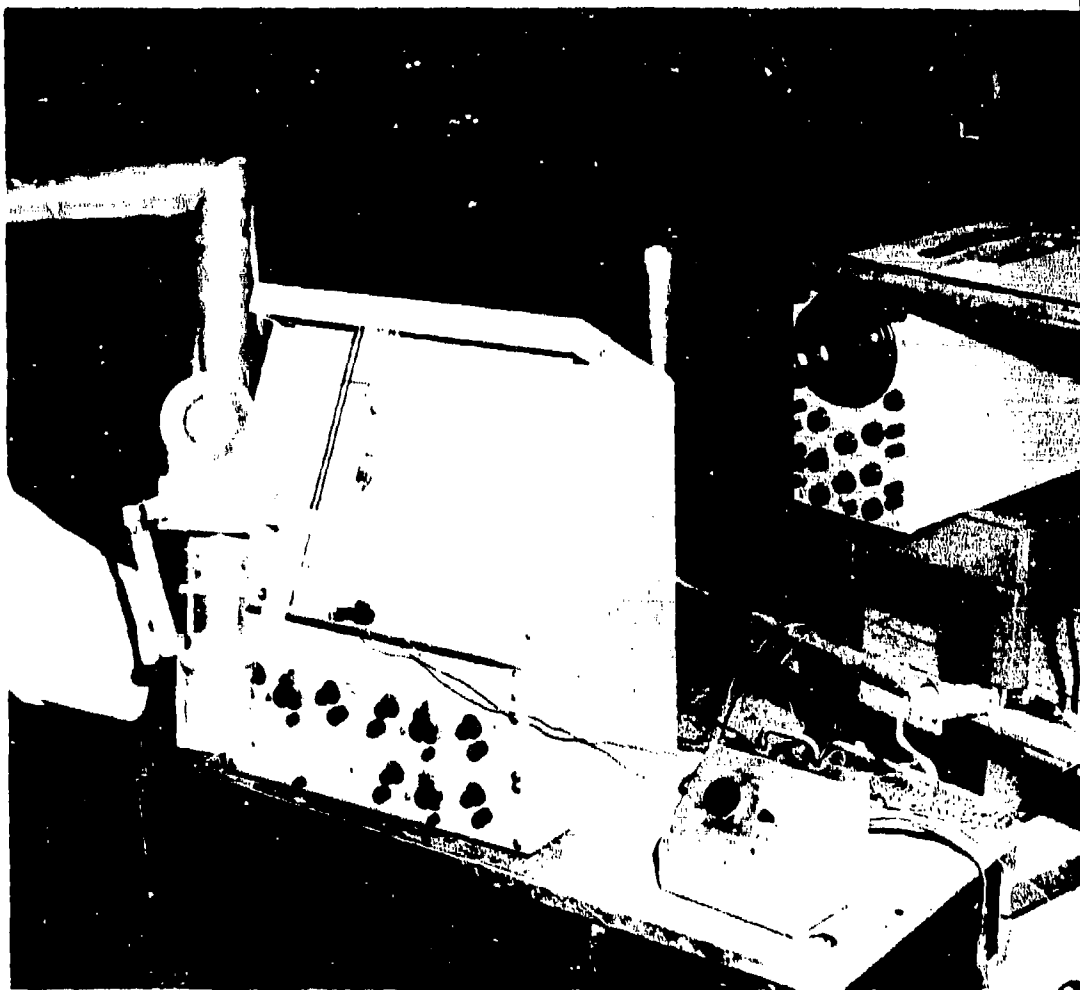


Figure 49. Improved REAC Simulator Display

E. RESULTS

Many of the results obtained during the course of stability and control investigations were not particularly gratifying. In most cases these results stem from limitations of the simulation. Because of these limitations, conclusions must be tempered with judgment. In what follows, an attempt has been made to use such judgment with respect to the significance of the results.

One phase of the studies included analog flights in which the operator attempted hovering turns. Altitude and heading were presented on the display shown in Figure 50. In this study, the effects of yaw control power and gradient were to be evaluated. Figure 51 shows three different functional relationships of yaw control power versus the yaw control grip angular deflection in percent. In Figure 51, the ordinate is the percent of available thrust which contributes to a yawing moment when the rocket nozzles are deflected. Thrust is not constant since fuel is consumed; therefore, the magnitude of the yawing moment varies during the course of flight. The actual yawing moment is given by

$$N = T \delta_{\eta} l$$

where N = yawing moment, ft-lb
 T = rocket thrust
 δ_{η} = nozzle deflection, rad
 l = distance from nozzle center line to cg, ft

The curve labeled "design" is representative of that existing on the actual SRLD hardware.

An evaluation of the effects of control power and control gradient necessitates that a significant performance parameter be used. Since both altitude and heading were variables, it seemed reasonable to choose altitude and heading deviations. This was done, and during the hovering turn flights the following observations were made:

1. Deviations of yaw angle while attempting to maintain a constant heading.
2. Deviations of altitude while attempting to maintain constant heading.

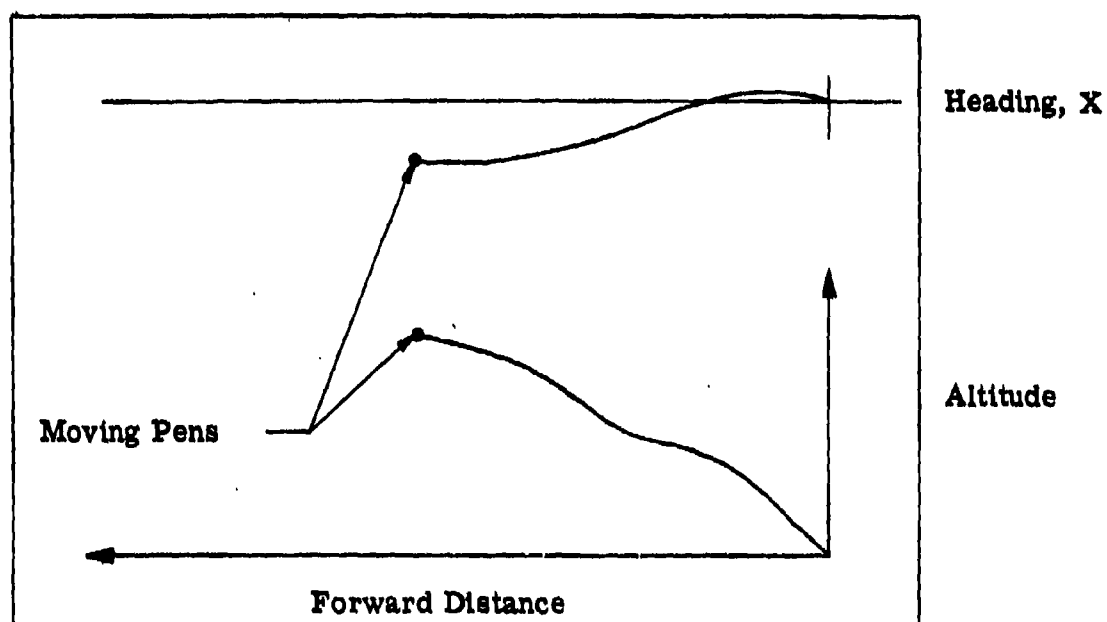


Figure 50. X-Y Plotter Display for Forward Flight

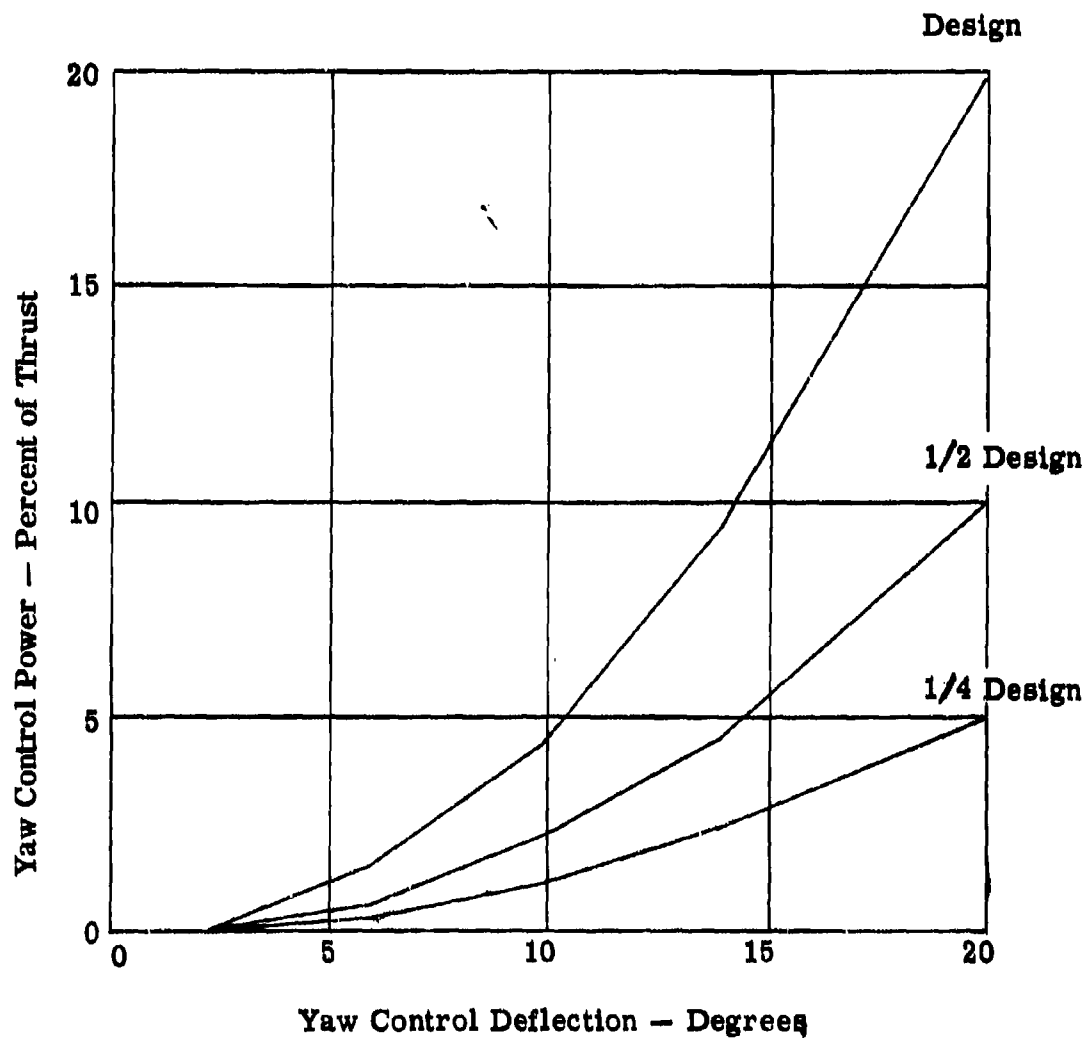


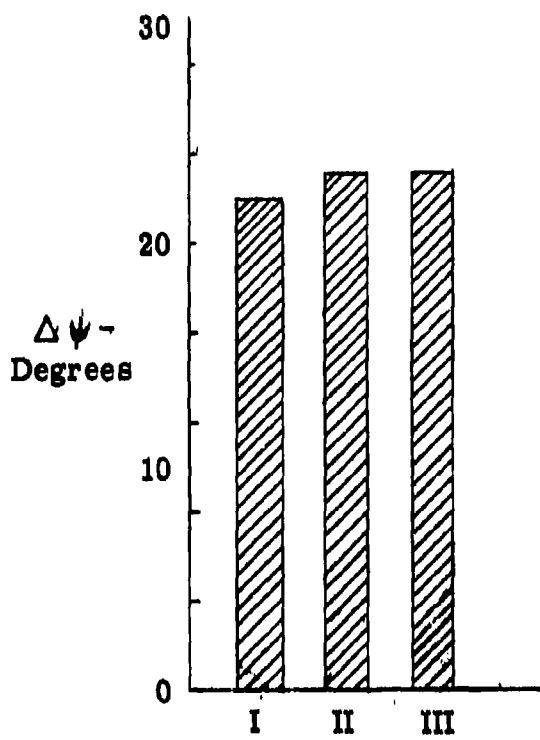
Figure 51. Yaw Control Sensitivities Used in Analog Simulation

3. Maximum overshoot of yaw angle when turning from an initial heading to a specified heading.
4. Altitude deviation while performing the task in 3 above.

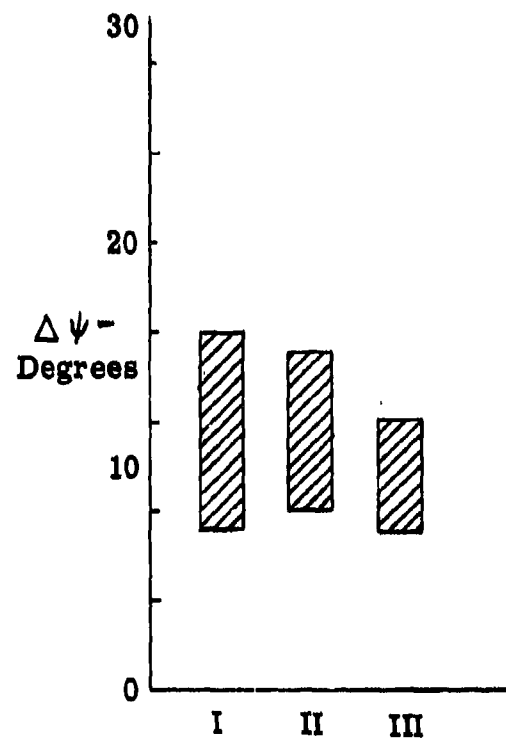
Figure 52 shows the results of these tests, with 52(a) and 52(b) corresponding to (1) and (2) above and 52(c) and 52(d) corresponding to (3) and (4) above. The shaded areas indicate the largest concentration of test results. Figures 52(a) and 52(b) show that yaw control power is not significant with respect to maintaining constant heading. The reason for the large heading deviations (up to over 20 degrees) is not quite clear. It seems that the operator was extracting yaw rate information from the scope in addition to yaw deviation; and as long as he could maintain the rate within his own acceptable limits, he allowed heading angle to build up and still consider the hovering flight as successful. Figure 52(c) lends some support to the fact that the operator was utilizing considerable rate information. The overshoot angles varied between 7 and 16 degrees, with a slightly narrower band for higher control power. The operator could initiate a hovering turn and utilize rate information quite well to prevent larger overshoots.

A glance at Figure 52 shows more variation in (c) and (d) than in (a) and (b). Operator's comments indicate that control power variations were not so much the cause for this variation as was the tendency to move the yaw control when the throttle was turned and vice versa. The task for Figure 52(c) and (d) required more yaw control movement and consequently was reflected in throttle motions and the corresponding altitude changes.

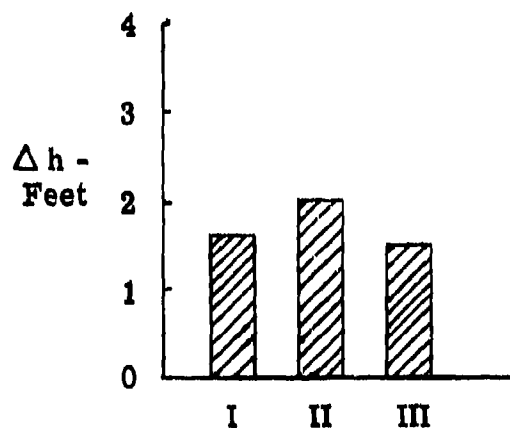
After developing the display of Figure 50 through trial and error, many longitudinal flights were made in which the operator controlled altitude heading and forward displacement. The trial and error procedure served to point out the necessity of a proper display. It is felt at this time that the display status leaves much to be desired and is primarily responsible for the limitations of the simulation. The longitudinal flights that were made showed that the operator had little difficulty if he controlled only the magnitude and direction of the resultant force through the system center of gravity and did not introduce moments. The ability to accelerate and decelerate rapidly while translating forward was related to display gain. When the operator became accustomed to one display gain, he could judge the motion of the pen on the x-y plotter so that it did not move off the paper. When the gain was changed without his knowledge, he immediately questioned



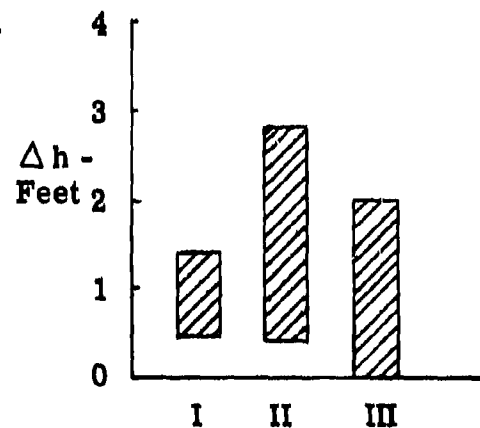
(a)



(c')



(b)



(d)

I, II, III refer to 1/4 design, 1/2 design, and design respectively. See Figure 51.

Figure 52. Test Results of Hovering Turn Studies

the operation of the equipment. The effects of adding pitching moment control were pronounced. Depending on the magnitude of the available control moment, the flights varied from controllable to uncontrollable, with smaller moments giving better control. An oscilloscope showing upper body pitch attitude was used with the x-y plotter. Addition of the oscilloscope to present a pertinent attitude parameter increased the task complexity and the operator had more difficulty in monitoring both displays to extract the proper cues and respond accordingly with control. Altitude control deteriorated only to the extent that the operator divided his monitoring time between observing altitude and pitch attitude.

After performing these flights, it became apparent that the displays were responsible for the majority of the simulation problems. It also became apparent that the two-segmented mathematical model is being used to its limits. In this model, the operator has no control over the relative angular displacement between the upper and lower bodies. He can exert considerable control in actual flight. This relative angular displacement does affect center-of-gravity location and can influence precise moment control. The effects of inertia moments due to dangling legs and variable moment of inertia due to propellant consumption are of secondary importance.

Attempts at optimizing control forces, gradients, and deflections cannot be carried out fruitfully if the results of tests depend greatly on factors such as display characteristics; and it is known that display characteristics can alter the system dynamics apparent to the operator. The effect of friction on the throttle was studied to a limited extent, and it was found that reducing friction was favorable from the operator's own personal "feel" standpoint but did not materially influence his analog flight performance. Attempts were also made to improve operator pitch control response by superimposing a pitch rate signal on the attitude signal presented on the oscilloscope. This would, in effect, present him with lead information concerning pitch attitude response. This was beneficial when high rates occurred but at lower rates showed no significant effect. Since high rates were developed by control motions which the operator felt were unrealistic, the value of presenting lead information was not established.

Another reason for mechanizing six-degree-of-freedom dynamics on the computer was to correlate results of theoretical studies with flight test data. These flight tests data were to be acquired by instrumenting the

SRLD with a telemetry system. The instrumentation and telemetry hardware were being developed under another contract, which was subsequently terminated due to the inability to achieve a workable data acquisition system within the allotted funds. Reference 4 outlines the scope of that contract and discusses the major problems which led to contract termination.

F. CONCLUSIONS

Yaw control power did not affect performance on simple two-degree-of-freedom analog flights in which altitude and heading were controlled. There was, however, a tendency to move the yaw control along with the throttle. Flight performance was improved when the operator learned to coordinate control movements properly.

Satisfactory translatable flights were performed when force control and no pitching moment control were used, but the addition of pitching moments increased the task difficulty. The lack of a proper display which could present all necessary cues in a manner which the operator could utilize efficiently to control the system dynamics prevented satisfactory complete six-degree-of-freedom flights from being accomplished.

Six-degree-of-freedom dynamics were mechanized on the computer for correlation of analog studies with flight test data. Difficulty in developing a workable telemetry and instrumentation system prevented this goal of acquiring flight test data from being achieved.

As a result of these computer studies, a secondary but important gain was made with respect to utilization of the simulator for training as a result of setting up the equipment properly in preparation for the above-mentioned data. The net result should be quicker, less costly pilot training in the future.

IV. HUMAN FACTORS

A. General

Human factors effort in the program encompassed the following activities:

1. Flight test program evaluation, including the following subtasks: establishment of trainee's control task; development of objective indices of performance; qualitative description of training flights; analysis of training performance; and evaluation of massed versus distributed practice effects.
2. Development of selection and training criteria.
3. Preparation of tethered and free-flight training program, including qualitative criteria for the determination of free-flight readiness.
4. Development of selection criteria and training requirements for maintenance and servicing personnel.

B. FLIGHT TEST PROGRAM

1. General Background

Establishment of Trainee's Control Task: The basic flight plan used in training consisted of simple horizontal translations that were increased in length as evidence of improved proficiency was manifested. All flights were performed in the Bell experimental hangar. A 100-foot yellow painted line, with 4-foot squares at each end and in the center, was used as a flight path reference. Figure 53 is a photograph of trainee on tether.

Development of Objective Indices of Proficiency: In an effort to achieve a more objective evaluation of operator proficiency, the adequacy of a set of indirect indicants of learning was explored. Assumptions governing the validity of these measures as indicants of learning are:

- a. The amount of fuel and its pressurization are constant throughout the trials to be compared, and
- b. The operator is attempting to remain airborne for the maximum time permitted by his fuel supply.



Figure 53. Trainee Performing Tethered Flight

The indicants include:

- a. Total thrust duration, which reflects learning in that the shorter the duration of thrust (down to a minimum of 22 seconds), the longer the device is airborne. Actuating the throttle at less than the level required to achieve airborne status results in longer duration of thrust; a decrease in thrust duration means that greater proficiency has been attained in achieving and maintaining flight.
- b. Number of attempts on the throttle, which represents the number of times an attempt is made to achieve airborne status. Decreases in this number indicate that longer flight periods are being maintained and that greater proficiency has been acquired.
- c. Average duration of each attempt, which is the mean value of the duration of flight attempts in a given trial. Increases in this measure are a function of longer airborne status per flight and, as a result, reflect greater proficiency.

It is apparent that the above indices, although they have the merit of being objective, are severely limited in their usefulness. The ability to stay airborne appears to develop rapidly and relatively early in training; consequently, these indices fail to reflect further increments in proficiency, such as accuracy and smoothness in the execution of maneuvers. They are not capable of isolating and assessing individual error sources, e.g., yaw or pitch control. Thus, it is apparent that to achieve greater precision in the rating of control performance, and changes in operation due to learning, a more refined measurement of system performance will be required.

In spite of these limitations, the utility of these indicants is demonstrated below in the discussion of results of the present training program. Their general graphical character displays a reasonable reflection of the incremental improvement to be expected in a learning situation.

Preflight and Auxiliary Training: Preflight training consisted of trainee observation of two tethered flights by the instructor. In addition, spaced practice on the REAC throttle control simulator was given for a total of one and one-half hours. The device consists of a SRLD-like harness with a right-hand throttle control, coupled with an oscilloscope

display. Throttle activation is represented on the scope by vertical deflections of the blip. Control-blip deflection ratios were selected to correspond to SRLD characteristics.

During the morning preceding the second training flight, the trainee received yaw control practice on the Bell air bearing platform. In this device, the trainee was seated on a stool which was mounted on the air bearing platform, with a control stick governing yaw movement at his left hand. By twisting the control stick in the direction of desired movement, the trainee could induce changes in orientation of the platform. It was felt that this experience would serve to develop proficiency in the use of left hand twisting movements for yaw control under conditions that would realistically duplicate the dynamics encountered in flying the SRLD.

2. Trainee Background

Mr. Peter Kedzierski, the trainee, is 19 years old and a recent graduate from a high school aviation mechanics program. His interest in this field is currently manifested by his enrollment in an evening school basic engineering science curriculum. Mr. Kedzierski is 5 feet 10-1/2 inches tall, weighs 155 pounds, and is of slim build. Motor skills acquired prior to the training program in which he currently participates include glider flying, gymnastics, roller skating, skiing, and some power flying. Since the beginning of the training program, he has taken up motor-cycling.

Qualitative Description of Training Flights: Qualitative descriptions of flights 1 through 28 are delineated below. Descriptive information includes flight plan and instructions; graphic description of performance; total thrust duration (in seconds); average time for each attempt (in seconds); and observers', instructor's, and trainee's postflight comments.

Training flight profiles are presented on the following pages. At takeoff, the trainee is facing in the general direction of the flight path indicated by the arrow heads.

Tethered Flight No. 1

January 31, 1962








3:00 pm

Flight Plan and Instructions: Obtain general familiarization with controls; perform straight "short-hop" translations.

Performance

Seven attempts were made in approximate profiles as follows:

Initial burst lasted 0.9 second as measured by stop watch.

1.  back off balance
2.  back off balance
3.  3-5 feet translation
4. 
running off laterally
5.  back off balance
6. 
running
approx. 1-foot altitude
7. 

Total thrust duration (as measured by stop watch): 35 seconds

Observer comments include: "... he appears to be raising legs before he has enough thrust for take-off ..." "... he got into trouble twice, off to the right ...", "tends to bend knees ..."

The instructor noted that it was a very promising first flight. The first few lift-offs were hover attempts with a slight amount of rearward travel. Forward travel seemed easier for him to control. The operator stated that he tended to drift rearward, which he countered with slight downward control. He also noted that he tended to retract his legs at lift-off.

Tethered Flight No. 2

February 1, 1962

3:00 pm



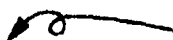
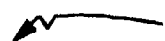
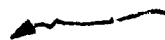



Flight Plan and Instructions: Same as previous flight.

NOTE: The trainee was provided with practice on a yaw control function, employing an air bearing stool with left-hand throttle control, in the morning of this day.

Performance

Eight attempts were made as follows:

Initial burst of 0.8 second (as measured by stop watch)

- | | | | | | |
|----|---|-------------|---|----|---|
| 1. |  | 4.7 seconds | | | |
| | slightly back | | | | |
| 2. |  | 6.3 seconds | | | |
| 3. |  | 4 seconds | | | |
| 4. |  | 3 seconds | | | |
| 5. |  | 2.7 seconds | | | |
| 6. |  | 7. |  | 8. |  |

Total thrust duration (as measured by stop watch): 29.0 seconds

Observer comments included: "... he's having trouble with roll, a little in yaw and in pitch ..." "... no confidence with altitude."

The instructor considered that progress was evident from the previous flight. A slight lateral "whip" seemed evident. He tended to drift to the right.

The operator stated that lateral control on this flight was most troublesome, as he tended to veer off to the right just after lift-off. The blast and heat bothered him when his leg got in it. He felt that he needed better control of his legs and more throttle practice.

Tethered Flight No. 3

February 2, 1962


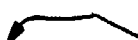



3:00 pm





Flight Plan and Instructions: Perform short translational hops up to 25 feet, for further pitch and throttle control practice.

Performance

Nine attempts were made as follows:

Initial burst of 0.5 second (as measured by stop watch)

- | | | |
|----|--|-------------|
| 1. |  | 3 seconds |
| 2. |  | 4 seconds |
| 3. |  | 4 seconds |
| 4. | 
slight turn | 5 seconds |
| 5. |  | 3.5 seconds |
- approx. 10-foot distance.

- | | | |
|----|---|-------------|
| 6. |  | 2.5 seconds |
| 7. |  | 3 seconds |
| 8. |  | 2.5 seconds |
| 9. |  | 1.8 seconds |

Total thrust duration: 28.3 seconds

Average duration of each attempt: 3.1 seconds

Observers commented that he tended to bank against the translation and that yaw still appeared to be a problem.

The instructor noted that lift-offs were too rapid and that the trainee was airborne before correcting his line-up error. Lateral correction appeared to be the major problem, with throttle control on ascent appearing to be too rapid and jerky. He rated the trainee 1-1/2 on the basis of ten being ready for free flight. The operator commented that he still had a tendency to slip to the right. The three to four feet of altitude he achieved he considered a new experience with the rig. He also noted feeling the propellant warning vibrator for the first time. He rated his control only 3/4 on the basis of ten being ready for free flight.

Tethered Flight No. 4

February 5, 1962





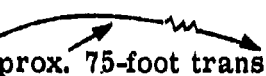


3:00 pm

Flight Plan and Instructions: Same as previous flight.

Performance

Seven attempts were made as follows:

Initial burst of 0.7 second

1.  2.5 seconds
2.  5 seconds
3.  6 seconds
4.  4 seconds
5.  6.3 seconds
6.  5.5 seconds
7.  1.2 seconds
out of propellant

Total thrust duration: 28 seconds

Average duration of each attempt: 3.9 seconds

Observers noted that he was running off the line.

The instructor noted that the trainee appeared to be very stiff during the first two hops and picked up a hard right yaw. He felt that the velocity and altitude were somewhat excessive, though controlled, at this stage of learning. He rated the trainee 4-1/2 on the basis of ten.

The trainee noted that he effectively used the yaw control during this flight. He felt that during the flight, the tether interfered with his control somewhat. He rated the flight 2.0 on the basis of ten being ready for free flight.

Tethered Flight No. 5

February 6, 1962




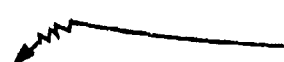


11:00 am

Flight Plan and Instructions: Same as previous flight.

Performance

Eight attempts were made as follows:

Initial burst of 0.5 second

1.  3.8 seconds
yawing
2.  3.9 seconds
yawed and balanced back
3.  3.5 seconds
turned and stumbled
4.  3.8 seconds
approx. 3-foot altitude, 10-foot translation
5.  4 seconds
running
6.  3.5 seconds
running

7.  4.5 seconds

8.  2.8 seconds
 leaning back

Total thrust duration: 3.6 seconds

Average duration of each attempt: 3.6 seconds

Observers noted: "... initial starts seemed to be with one shoulder down." "... always off to the right ..." "he puts his shoulder down when he starts to squeeze the throttle ..." "... his stance seemed to be off at the start. ..."

The instructor commented that almost all attempts evidenced excess lateral deviation. He rated the overall flight only 3-1/2 on the basis of 20 being ready for free flight. Twenty flights are the estimated number required for free-flight qualification. Prior flights used an arbitrary number of 10 for reference.

The trainee considered lateral control to be his main problem since he tended to drift to the right. He also noted a problem with pitch where he initially applied too much or too little at the start. His feet tended to get into the jet stream; nor did he feel the propellant warning vibrator. His whole trouble, he felt, was in lining up the nozzles laterally. He rated the flight only 3/4 on the basis of 20 being ready for free flight.

Tethered Flight No. 6

February 6, 1962


3:00 pm








Flight Plan and Instructions: Same as previous flight.

Performance

Eight attempts were made as follows:

Burst of 0.6 second

1.  4.4 seconds
 yawed

2.  2.9 seconds
3.  2.8 seconds
lateral and lift trouble
4.  6 seconds
off line and yawed
5.  4.5 seconds
off line and yawed
6.  3.4 seconds
off line to right and running
7.  3 seconds
right off line
8.  2.7 seconds
out of propellant

Total thrust duration: 28.7 seconds

Average duration of each attempt: 3.5 seconds

Observers comments included: "... seemed to have yaw trouble coming and roll or sideward translation going back ..." "... pitch trouble on short hops ..." "... probably rides constant throttle ..."

The instructor commented that starts were made with backward and lateral jerks, and that trouble appeared to be at lift-off and low level.

The trainee noted that initially he was not applying enough pitch for forward translation. He was still getting his foot into the jet stream, and did not feel the propellant warning vibrator signal.

Tethered Flight No. 7

February 7, 1962




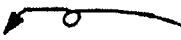

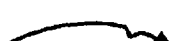
11:00 am

Flight Plan and Instructions: Perform 50-foot translational hops, obtain pitch and throttle practice, and yaw and lateral control.

Performance

Eight attempts were made as follows:

Initial burst of 0.7 second

1.  4.1 seconds
yawed
2.  1.2 seconds
back off balance
3.  3.7 seconds
off backwards and laterally
4.  4.1 seconds
5.  3.9 seconds
right off line
6.  4 seconds
yawed right

7.  3.6 seconds
running

8.  1.3 seconds
out of propellant

Total thrust duration: 3.1 seconds

Average duration of each attempt: 3.1 seconds

Observers noted that he tended to deviate to the right and that the operator appeared to be aware of deviations developing.

The instructor commented that improper initial stance at start, with nozzles so oriented, tended to induce motion backwards and laterally. Initial lift-off, then, appeared as the major problem. Next flight was to use a tank pressure 10 lb/in.² lower, with the intention of firing on the ground at detent level to get the feel of nozzle positioning. He rated the flight 5 on the basis of 20.

The trainee considered pitch to be his major problem. His biggest concern he considered his starting stance. He felt that in concentrating so hard on other aspects of his flight, he failed to notice the propellant warning vibrator.

Tethered Flight No. 8

February 8, 1962

3:30 pm


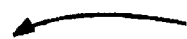





Plan and Instruction: Apply throttle slowly to assure obtaining proper nozzle angle for lift-off and translation.

Performance

Seven attempts were made as follows:

NOTE: All times indicated were stop watch measurements on throttle actuation.

Burst of 0.6 second

1.  3.9 seconds
turned and crabbed
2.  4.8 seconds
3.  3.9 seconds
turned and set down off line
4.  4.3 seconds
running
5.  3.8 seconds
turned left at set down
6.  3.2 seconds
7.  1.5 seconds
out of propellant

Total Thrust Duration: 25.9 seconds

Average duration of each attempt: 3.6 seconds

Observer comments included: "... he's making progress ... he was bouncing a bit, but stayed on the line ...", "he now acts on small deviations to correct them out."

The instructor noted that lateral and/or yaw problems developed shortly after lift-off. He concluded that smooth lift-offs were now indicated and in-flight problems were becoming more in evidence. The tank pressure was to be reduced for the next flight to aid the trainee in performing smooth lift-off. He rated the flight "5" on the basis of 20 being qualified for free flight.

The trainee stated that pitch and throttle control were his main concern on this flight. He felt that he was controlling the position of his legs and pitch, lateral and yaw control more smoothly. He rated the flight "5".

Tethered Flight No. 9

February 9, 1962

11:00 am

Flight Plan and Instructions: Same as previous flight (tank pressure reduced by 10 psi)

Performance

Eight attempts were made as follows:


Burst of 0.6 second

1. 10 ft  4.2 seconds
legs swung out

2.  4.2 seconds
Off line

3.  4.8 seconds

4.  2.2 seconds
back off balance

5.  4.2 seconds
laterally off to the right

6.  2.9 seconds
laterally off

7.  3.6 seconds
10 ft translation

8.  1.0 second
out of propellant

Total Thrust Duration: 28.3 seconds

Average duration of each attempt: 3.6 seconds

Observers' comments included: "... needs just a slight more forward thrust for takeoff and faster throttle . . .", "legs are caused to swing forward . . .", "seems to be trying to lift himself up and puts the nozzles in a backward position".

Tethered Flight No. 10

February 12, 1962


3:00 pm

Flight Plan and Instructions: Same as previous flight
(50-foot translations)

Performance

Six attempts were made as follows:


Burst of 0.5 second


1.  3.9 seconds
legs swung sideways and forward

2.  4.6 seconds

3.  4.0 seconds

4.  5.5 seconds
25 feet
moved off sideways slightly

5.  5.0 seconds
50 feet

6.  2.1 seconds
20 feet
out of propellant

Total Thrust Duration: 25.6 seconds

Average duration of each attempt: 4.2 seconds

Observer commented that he was slow to lift-off and translate and that he seemed to control the deviations well.

The instructor noted that the trainee developed a violent sway in the hover position. He considered that improvement was shown in the lift-off. He rated the flight "8" on the basis of 20.

The trainee felt that he was "catching on" but that he got into trouble trying to hover before translating. He rated the flight "9" on the basis of 20.

Tethered Flight No. 11


February 13, 1962


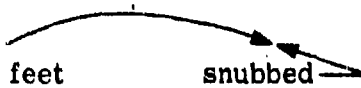

11:00 am

Flight Plan and Instructions: Same as previous flight.

Performance

Four attempts were made as follows:

1.  75 feet
yawed right

2. 
25 feet
3. 
50 feet fast
4. 

Observers commented that he built up a strong right yaw; he could not correct it.

The instructor noted that the translations were fast and uncorrected yaw was operating. He rated the trainee "10" on the basis of 20.

The trainee stated that he could get off the ground smoother, land better, and that he could concentrate on coordinating the controls. He also rated the flight "10".

Tethered Flight No. 12

February 13, 1962

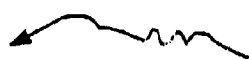
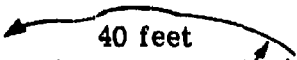
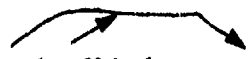
3:00 pm




Flight Plan and Instructions: Same as previous flight
(Perform 50-foot translations)

Performance

Six attempts were made as follows:

Burst of 0.4 second

1. 
30 feet 6.3 seconds
Some yawing occurred with pendulum-like leg action
2. 
40 feet 7.1 seconds
running straight and steady
3. 
4 seconds
back off balance a bit

4.  3.9 seconds
5.  3.5 seconds
straight and steady
6.  0.8 second
out of propellant

Total Thrust Duration: 26 seconds

Average duration of each attempt: 5.1 seconds

Observers commented that he seemed to be pitching up in deliberate braking control and that he seemed to be correcting in roll.

The instructor noted that body-swinging gyrations seemed to be causing the most in-flight problems necessitating a letdown. He considered that the trainee performed the first well-controlled letdown. He rated the flight "9".

The trainee noted that he seemed to be having trouble with yaw, and that he needed more practice in overall coordination. The yaw problem he attributed to possible hand interference, or a misalignment of the jetavators. He rated the flight "10".

Tethered Flight No. 13

February 14, 1962

3:00 pm


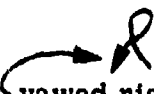
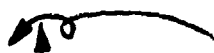

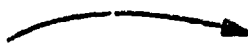

Flight Plan and Instructions: Same as previous flight.

NOTE: Upon advice of medical personnel, additional padding was provided at each arm-ring clamp.

Performance

Six attempts were made as follows:

Burst of 0.3 second

1.  3.2 seconds
off to the right
2.  5.5 seconds
yawed right
3.  6.2 seconds
turned and snubbed
4.  4.8 seconds
5.  5.2 seconds
50 feet
running
6.  0.3 second
out of propellant

Total Thrust Duration: 25.5 seconds

Average duration of each attempt: 4.2 seconds

Observers commented as follows: "... should give him some throttle maneuvers, seems like most trouble is in landing" "... attitude trouble ...".

The instructor noted that the trainee had lateral control difficulties and a throttle control problem. Adverse body swinging subsequent to lift-off tends to spoil flight. He rated the flight "9" on the basis of 20.

The trainee considered yaw his major problem, seeming to be induced at throttle actuation. He felt this could be avoided by grasping the yaw handle at the base. Legs dangling he also considered to be problematic. He rated the flight "10".

Tethered Flight No. 14



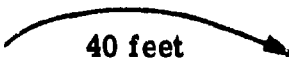
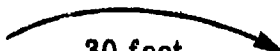
February 15, 1962

11:00 am

Plan and Instructions: Same as previous flight.

Performance

Four attempts were made as follows:

- Burst of 0.6 second
1.  8.2 seconds
50 feet
yawed and crabbed a bit
 2.  6.4 seconds
50 feet
 3.  6.4 seconds
40 feet
straight and steady
 4.  4.3 seconds
30 feet

Total Thrust Duration: 25.9 seconds

Average duration of each attempt: 6.4 seconds

Observers commented that he got into a little trouble in roll and raised the question if it might have been due to hand interference in throttle control.

The instructor noted that a half right yaw error occurred in the early flight that was out of control. Subsequently, he considered the flight excellent with much improvement. He rated it "13" on the basis of 20.

The trainee thought that he had then surely beaten the yaw problem by grasping the yaw control at the bottom of the handle. In so doing he felt he kept his left hand from moving with his throttle hand. He rated the flight "14".

Tethered Flight No. 15

February 15, 1962

3:00 pm


Plan and Instructions:

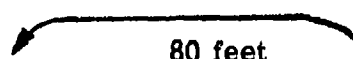
Same as previous flight.


Performance

Four attempts were made as follows:

Burst of 0.5 second

1.  4.4 seconds
lateral pendulum-like leg action

2.  11.3 seconds
80 feet
pitch oscillation, yawed and rolled slightly.

3.  6.1 seconds
50 feet
running

4.  2.8 seconds
out of propellant

Total Thrust Duration:

25.2 seconds

Average duration of each attempt: 6.2 seconds

Observers commented that he had improved tremendously from earlier flights. His biggest problem this time, it was stated, seemed to be in pitch in a fore-aft pendulum-like leg action. He seemed to do better when moving at a fairly good forward speed.

The instructor felt that problems in body swinging, yaw correction, deceleration and landing needed work. He rated the flight "12" on the basis of 20.

The trainee stated that he had a recurrence of the pendulum-like action of the legs, which was likely due to slow lift-off. This action, however, he felt he now controlled in flight better than earlier. He rated the flight "13".

Tethered Flight No. 16

February 16, 1962

3:00 pm



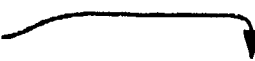

Plan and Instructions:

Same as previous flight.

Performance

Four attempts were made as follows:

Burst of 0.6 second

1.  5.5 seconds
back off balance
2.  10.1 seconds
75 feet
crabbed a bit
3.  8.9 seconds
4.  1.2 seconds
out of propellant

Total Thrust Duration:

26.3 seconds

Average duration of each attempt:

6.4 seconds

Observers commented that for some reason he had a hard right roll and some pitch trouble. He cut the throttle somewhat abruptly on the hop back.

The instructor noted that the body-swinging problem was still present and that he cut the throttle while 3 feet in the air. He rated the flight "12.5" on the basis of 20.

The trainee stated that he used the lateral control to cancel out the swinging of his legs. He unknowingly cut the throttle in landing after the buzzer came on. He rated the flight "13".

Tethered Flight No. 17

February 19, 1962

11:00 am

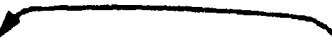
Plan and Instructions:

Same as previous flight.

Performance

Three attempts were made as follows:

Burst of 0.8 second

1.  15.8 seconds
100 feet

2.  7.4 seconds
yawed somewhat

3.  0.6 second
out of propellant

Total Thrust Duration:

24.6 seconds

Average duration of each attempt: 7.4 seconds

Observers commented "... that's the best one yet ...".

The instructor considered the flight to be excellent; the operator, he noted, apparently could not descend rapidly enough at the detent thrust level. He rated the flight "17".

The trainee stated that everything went well; he felt that more practice was needed for better throttle control and pitch in translation. He rated the flight "16".

Tethered Flight No. 18

February 19, 1962

2:30 pm

Plan and Instructions:

Same as previous flight.

Performance

Three attempts were made as follows:

Burst of 0.5 second

1.  10.8 seconds
50 feet
snubbed back off balance

2.  9.2 seconds
50 feet
controlled letdown

3.  4.1 seconds
running - out of propellant

Total Thrust Duration:

25.4 seconds

Average duration of each attempt: 8.1 seconds

Observers commented that he still had a bit of yaw and feet-swinging problem but he controlled it. He seemed to be getting more confident since he went higher. Also, he seemed to be attempting to correct roll by yawing.

The instructor noted that some body swing was induced at lift-off, but was damped out as he began to move. He was off laterally, and may have stumbled at let-down if tether assistance had not been provided. The instructor rated the flight "17".

The trainee noted that his biggest problem was his feet swinging, but he began to control them near the let-down point. He rated the flight "17".

Tethered Flight No. 19

February 20, 1962

11:00 am

Plan and Instructions:

Same as previous flight.


Performance

Four attempts were made as follows:

Burst of 0.4 second

1.  7.9 seconds
50 feet
off line at let-down

2.  6.8 seconds
50 feet
short of mark

3.  8.7 seconds

4.  1.9 seconds
out of propellant

Total Thrust Duration:

25.7 seconds

Average duration of each attempt:

6.2 seconds

Observers commented: "... everything seemed to be getting routine . . ." "... don't like his legs forward in landing - he would seem to have a tendency to fall back . . .".

The instructor considered control to be very good, but that he was slightly off balance at landing, and may have fallen without tether assistance. He rated the flight "17.5".

The trainee considered that he needed a little more yaw practice, though he thought he was controlling it reasonably well. He also felt that he needed more practice in take-off and landing. He rated the flight "18".

Tethered Flight No. 20

February 20, 1962

2:30 pm

Plan and Instructions:


Same as previous flight.

Performance

Five attempts were made as follows:

Burst of 0.4 second

1.  5.1 seconds
25 feet yawed and rolled
running

2.  7.0 seconds
40 feet

3.  6.4 seconds
50 feet on target

4.  4.4 seconds

5.  1.2 seconds
out of propellant

Total Thrust Duration:

24.5 seconds

Average duration of each attempt:

4.8 seconds

Observers comments included "... still throttle yaw coupling. Seemed like yaw trouble left - rolled right, over-controlled and had oscillations... " "... tended to left yaw on the touchdown ".

The instructor noted that the body-swing problem was evident shortly after lift-off. He considered all hops safe, but the lift-off to be sluggish. He rated the flight "18".

The trainee stated that he still had trouble in overall coordination. The slow throttle response may have been responsible. He also rated the flight "18".

NOTE: Following Mr. Kedzierski's Flight Number 20, a meeting was held by Project, Flight, Test, Medical and Human Factors personnel to determine Mr. Kedzierski's readiness to attempt free flight. The criteria discussed were primarily those of flight safety; i.e., that the trainee was not likely to stumble or fall. Some felt that his take-off performance was still not consistent enough. It was also considered that he should make his initial free-flight attempts over soft sod rather than concrete. It was finally agreed that subsequent tethered flights should be regarded as free-flight qualification flights, and critically observed for the trainee's readiness to begin free flight.

Tethered Flight No. 21

February 21, 1962

11:00 am

Plan and Instructions:

Same as previous flight (to observe for free-flight qualification)


Performance


Five attempts were made as follows:


Burst of 0.8 second

1.  8.3 seconds
50 feet
one-foot landing

2.  7.7 seconds
50 feet
smooth, straight and steady

3.  25 feet
legs dangled a bit 5.4 seconds

4.  3.0 seconds
hover attempt - lift-off to right

5.  0.6 second
out of propellant

Total Thrust Duration: 25.8 seconds

Average duration of each attempt: 5.0 seconds

Observers commented "... nervous throttle - bounced a bit to the right ...". "... excellent flight, he's ready right now ...". The tether man stated that he provided no assistance to the trainee.

The instructor considered this qualification flight number one as safe. He rated the flight "19".

The trainee felt that he had everything under control. He rated the flight "21".

Tethered Flight No. 22

February 23, 1962

11:00 am

Plan and Instructions:

Same as previous flight (second qualification flight)


Performance

Four attempts were made as follows:

Burst of 0.8 second

1.  35 feet 6.2 seconds

2.  50 feet
tripped a bit 9.1 seconds

3.  50 feet
straight and steady 6.9 seconds

4.  4.2 seconds
hover attempt

Total Thrust Duration: 27.2 seconds

Average duration of each attempt: 6.6 seconds

Observers commented that he had a yaw problem on the first attempt, and that the landing was rough on the second. The tether man helped him.

The instructor considered that the lift-off and landing problem necessitated three additional qualification flights. He rated the flight only "14".

The trainee felt that he performed poorly, because he was suffering from a cold. He rated the flight "20", however.

Tethered Flight No. 23

February 26, 1962

2:30 pm


Plan and Instructions:

Same as previous flight (third qualification flight).

Performance

Three attempts were made as follows:

Burst of 0.7 second

1.  50 feet
yawed slightly - corrected 11.6 seconds

2.  50 feet
straight and steady 9.5 seconds

3.  hovering attempt 3.5 seconds

Total Thrust Duration: 25.3 seconds

Average duration of each attempt: 8.1 seconds

Observers commented that he had his feet together when coming in for a landing, on heels and off balance - should spread his feet somewhat.

The instructor considered that the speed was unnecessarily slow, but that was an acceptable qualification test. He rated the trainee "21".

The trainee stated that he was more confident and found it much easier to fly. He rated the flight "22".

Tethered Flight No. 24

February 27, 1962

Plan and Instructions:


Perform short 25-foot translations as will be done in free flight (fourth qualification flight)



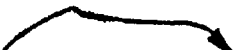

NOTE: The instructor's plan and free flight was to fly the trainee under tether. When the trainee felt he was ready during any given flight, the tether cable was to be removed.

Performance

Five attempts were made as follows:

Burst of 0.7 second

1.  4.4 seconds
leg swing caused abort

2.  25 feet 6.7 seconds
3.  40 feet 6.5 seconds
4.  25 feet 4.2 seconds
5.  7.3 seconds
run out of propellant

Total Thrust Duration: 29.1 seconds

Observer commented that he appeared initially to have gotten into pitch trouble coupled with yaw. No tether assistance was provided.

The instructor noted the trainee had a right lateral control problem. He considered, however, that this qualification flight was acceptable and rated the trainee "21".

The trainee noted that his legs still had a tendency to swing at the hips. He rated the flight "21".

Tethered Flight No. 25

February 27, 1962

2:30 pm


Plan and Instructions:

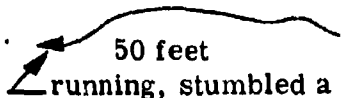


Same as previous flight (fifth qualification flight)

Performance

Four attempts were made as follows:

Burst of 0.6 second

1.  3.4 seconds
left yaw trouble

2.  50 feet 9 seconds
running, stumbled a bit
3.  50 feet 8.5 seconds
4.  10 seconds
run out propellant

Total Thrust Duration: 31.5 seconds

Observers stated that the first time he must have been leaning forward, for he accelerated forward at the same time. It was noted that in this flight difficulty was encountered with the trolley tether. (A different trolley-tether operator had been employed.)

The instructor considered that due to interference by the horizontal tether, the flight could not be accurately evaluated. He rated it only "14".

The trainee felt that he initially had the nozzles too far forward and started off too fast. He felt his trouble was a combination of poor coordination and tether interference, rating it "20".

Tether Flight No. 26

March 1, 1962

2:30 pm

Plan and Instructions:

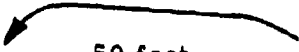
Same as previous flight.

Performance


Four attempts were made as follows:

Burst of 1.0 second

1.  25 feet 5.8 seconds
yawed and corrected

2.  50 feet
straight and steady 9.7 seconds

3.  7.4 seconds
yawed and corrected

4.  2.8 seconds
hover and run out of propellant

Total Thrust Duration: 26.7 seconds

Observers noted that there was no tether assistance nor interference.

The instructor considered the control to be good, landings safe, and unassisted. He rated the flight "20".

The trainee felt that he was learning to damp out the foot-swing. He described it somewhat as jumping on a trampoline where you hold the feet out and they stop. He rated the flight "25".

Tethered/Free Flight No. 27(1) March 2, 1962 2:30 pm

Plan and Instructions: Perform 25-foot translation under tether, followed by a 50-foot translation free of tether.



Performance

Four attempts were made (two free flight) as follows:

Tethered

1.  6 seconds
20 feet

Free Flight

1.  2 seconds
left lateral start and abort
2. 
40 feet
touchdown briefly at midpoint

Tethered

2. 
50 feet

The instructor noted that the first free flight was accomplished. He rated the flight "21".

The trainee stated that he felt no difference in flying free than under tether, except that he was more careful about erratic control movements. He rated the flight "26".

Tether Flight No. 28

April 10, 1962

2:30 pm

NOTE: This training flight was accomplished under tether in final preparation for outdoor free flights. It is of interest to note that after 5-1/2 weeks of no further training, the trainee's skill retention appeared to be complete. The trainee felt that he had complete control and was ready at any time for free flight.





The trainee stated that he didn't think it would come back to him after such a long layoff but it did. He tended to overcontrol yaw a bit initially but then got the feel of it.

Plan and Instruction: Perform short translational hops as desired.

Performance

Four attempts were made as follows:

Check Burst: 0.7 second (stop watch measurements)

1.  15 feet control good 7.1 seconds
2.  48 feet 11.1 seconds
slow and controlled
3.  20 feet 4.2 seconds
4.  3.2 seconds
run out of propellant at low thrust

Total Thrust Duration: 26.4 seconds

Observers commented that it was an excellent flight, and that he seemed to have real good control.

The instructor noted that all flights were safe and fully controlled. Lands were safe and smooth. He rated the flight "25" on the basis of "20" being ready for free flight.

3. Analysis of Training Performance

The new operator, as with the two previous operators, has evidenced considerable apprehension in flying the rig. Figure 54 presents maximum pulse-rate measurements obtained usually immediately following each flight. Note that for operators 1 and 3 (the new operator), no appreciable fall off in pulse rate occurred for the first eleven flights. No significant performance correlation, however, is suggested from review of performance data.

From review of the data obtained on the first 28 flights (including untethered translations), several objective indices of learning become evident. It is assumed that (1) the propellant load and tank pressures were constant for all flights (which was the case except for a small

Key:

- = Operator 1 - W.F. Moore
- - ○ = Operator 2 - H. M. Graham
- ▽- - ▽ = Operator 3 - P. L. Kedzierski

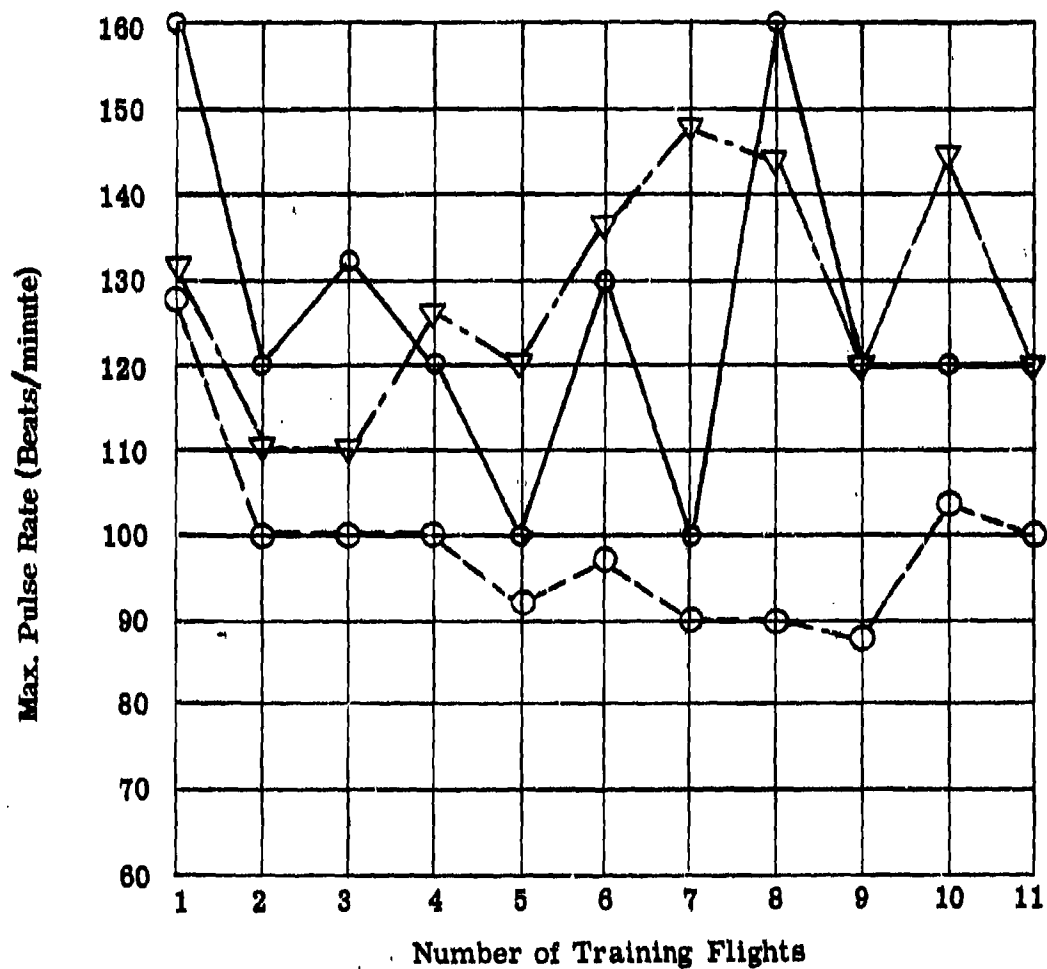


Figure 54. Operator Maximum Pulse Rate Versus Number of Flights

order of variation in tank pressure) and (2) within limits the trainee was attempting to maintain lift as long as he could each time he tried. In general, the latter assumption was also true for the first 23 flights, since the trainee frequently made such comments as, "I'll go farther if I can. Eighty feet is the maximum so far". Figures 55, 56, and 57 present plots of increasing proficiency as a function of: decreasing thrust duration, decreasing number of attempts for each flight, and an increasing average duration of each attempt in successive flights. These "learning curves" are based on the foregoing assumptions. The parameters are plotted only against the first 23 flights, since on later flights the trainee was instructed to perform only 25-foot translations preparatory to a similar free-flight pattern, which he was able efficiently to do, and no longer tried to go as far as he could; i.e., assumption No. 2 above was then not valid.

Total Thrust Duration (Figure 55). This parameter was a stop-watch measurement, signalled by the trainee's turning on and off of throttle; i.e., a measure of any thrust level at all was recorded as time. The time measured would thus decrease (to a minimum of approximately 22 seconds) with increasing proficiency as the trainee remained aloft for a greater proportion of the flight. Subsequent to Flight No. 23, the trainee was running propellant out on the ground, thus making this, as a proficiency index, meaningless.

Number of Attempts on Throttle (Figure 56). This measure was simply the number of times the trainee actuated the throttle for a given flight. With increasing proficiency, except where short translational flights were indicated, the trainee tended to make fewer attempts in each succeeding flight.

Average Duration of Each Attempt (Figure 57). This is the mean value of the duration of all attempts made during each flight; i.e., \bar{t}/N . With increasing proficiency and within the limits of the flight plan, this value is seen to increase.

Figure 58 presents a plot of the instructor's and trainee's independent ratings for each succeeding flight. This may be considered as a measure of subjective confidence of the trainee's ability to perform free flight, where "20" was taken to be the "100%-ready" value. Note that the independent ratings tended to correspond, though the plot suggests that the trainee was somewhat more confident of his controllability than was the instructor, especially in later flights.

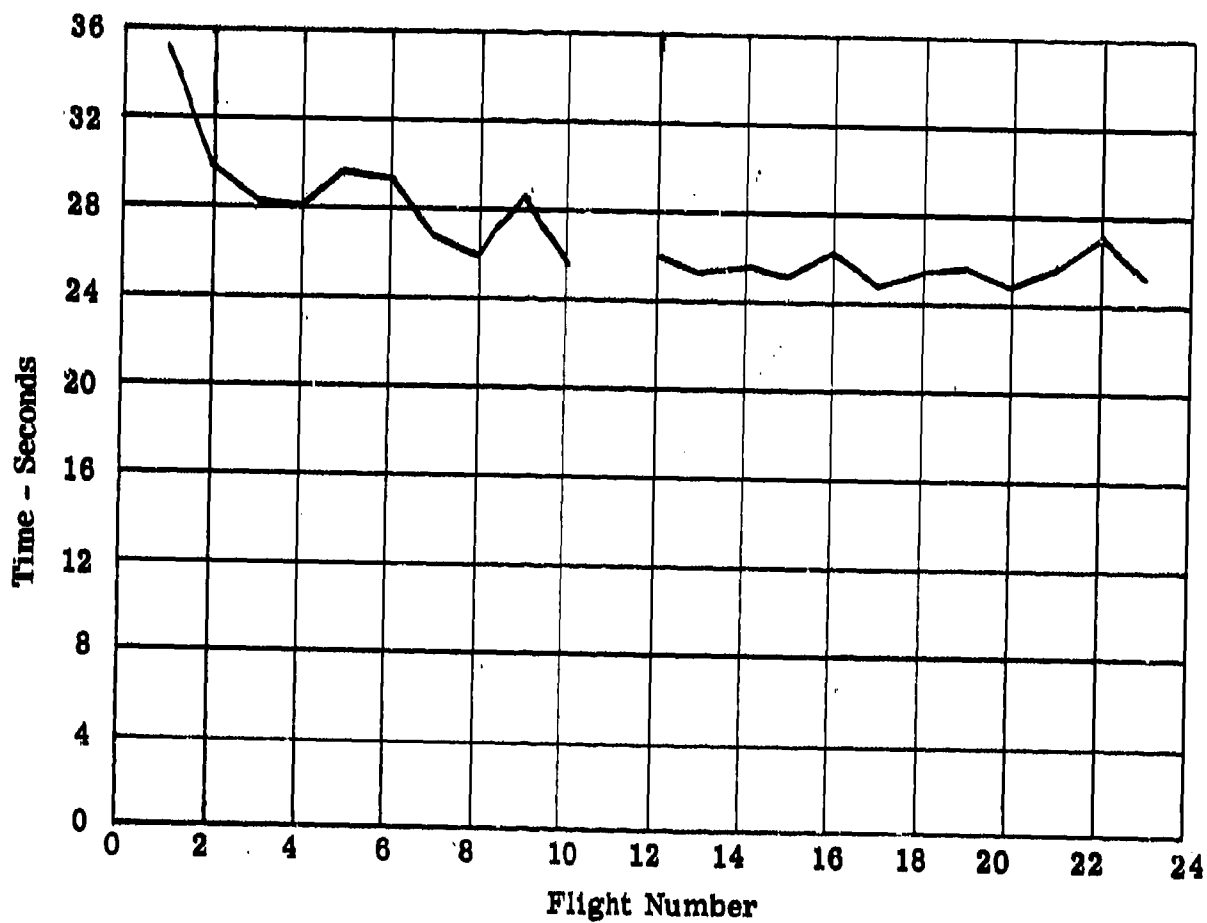


Figure 55. Skill Acquisition as a Function of Total Thrust Duration

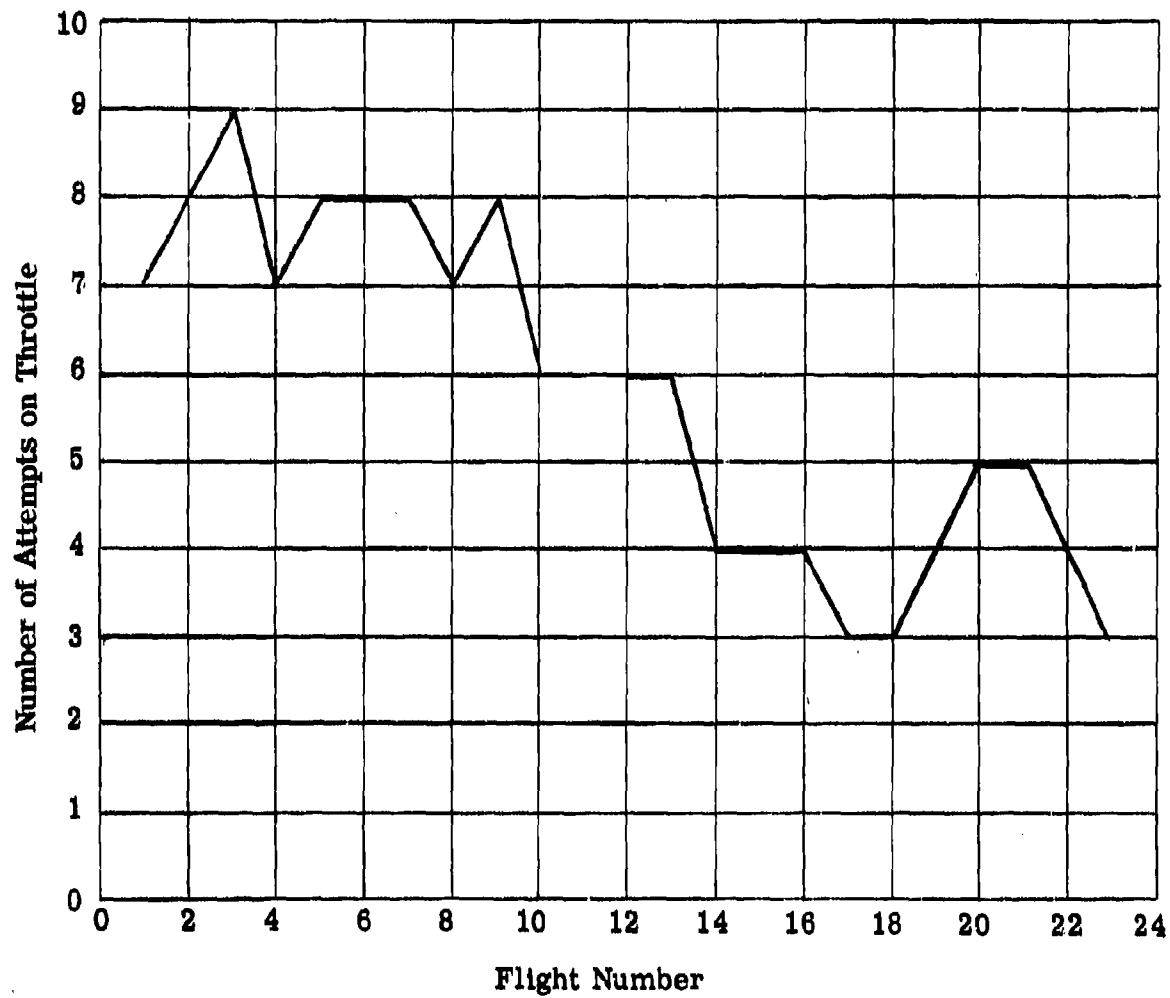


Figure 56. Skill Acquisition as a Function of Number of Attempts on Throttle Per Flight

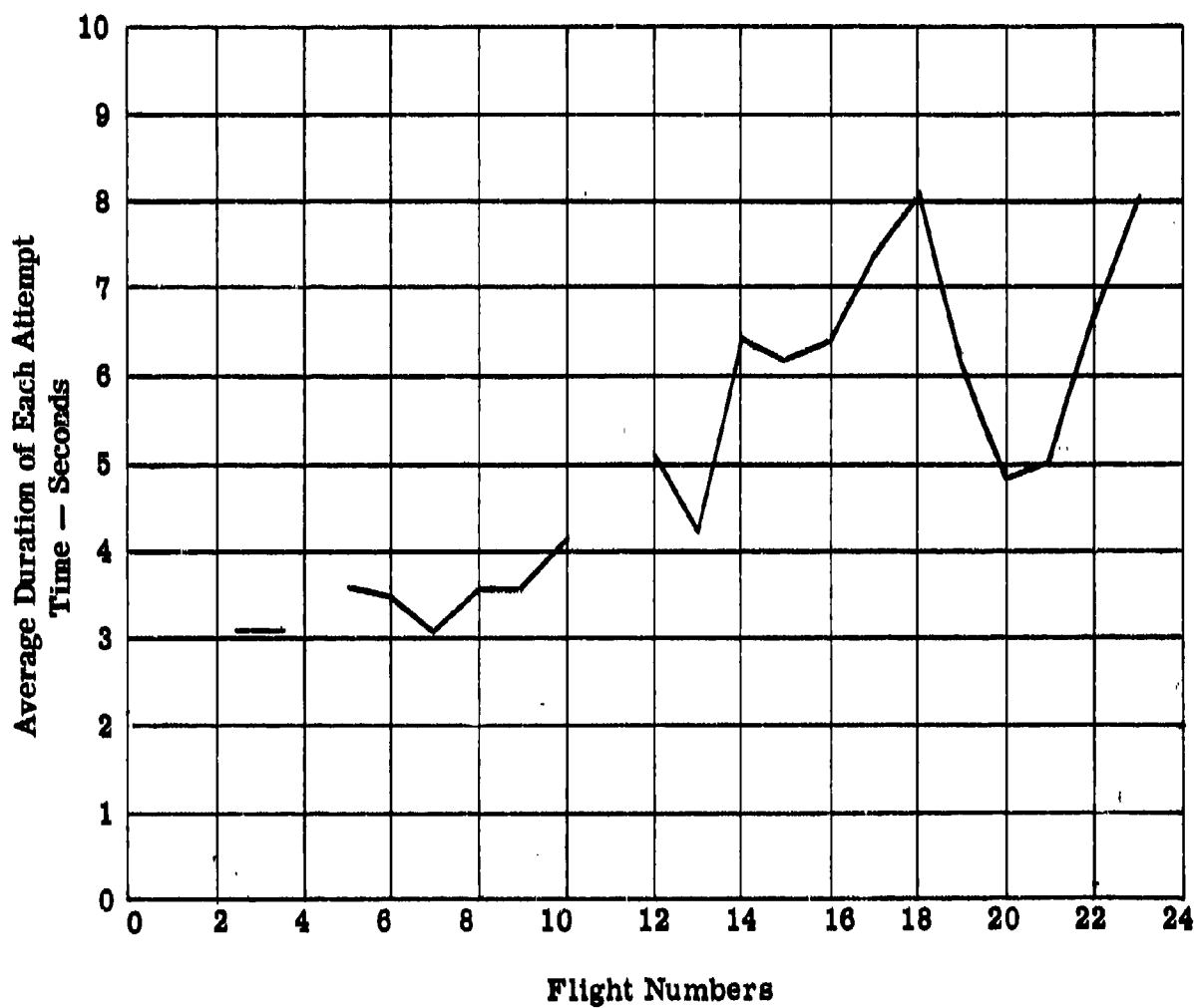


Figure 57. Skill Acquisition as a Function of the Average Duration of Attempts Per Flight

Relative Proficiency Level

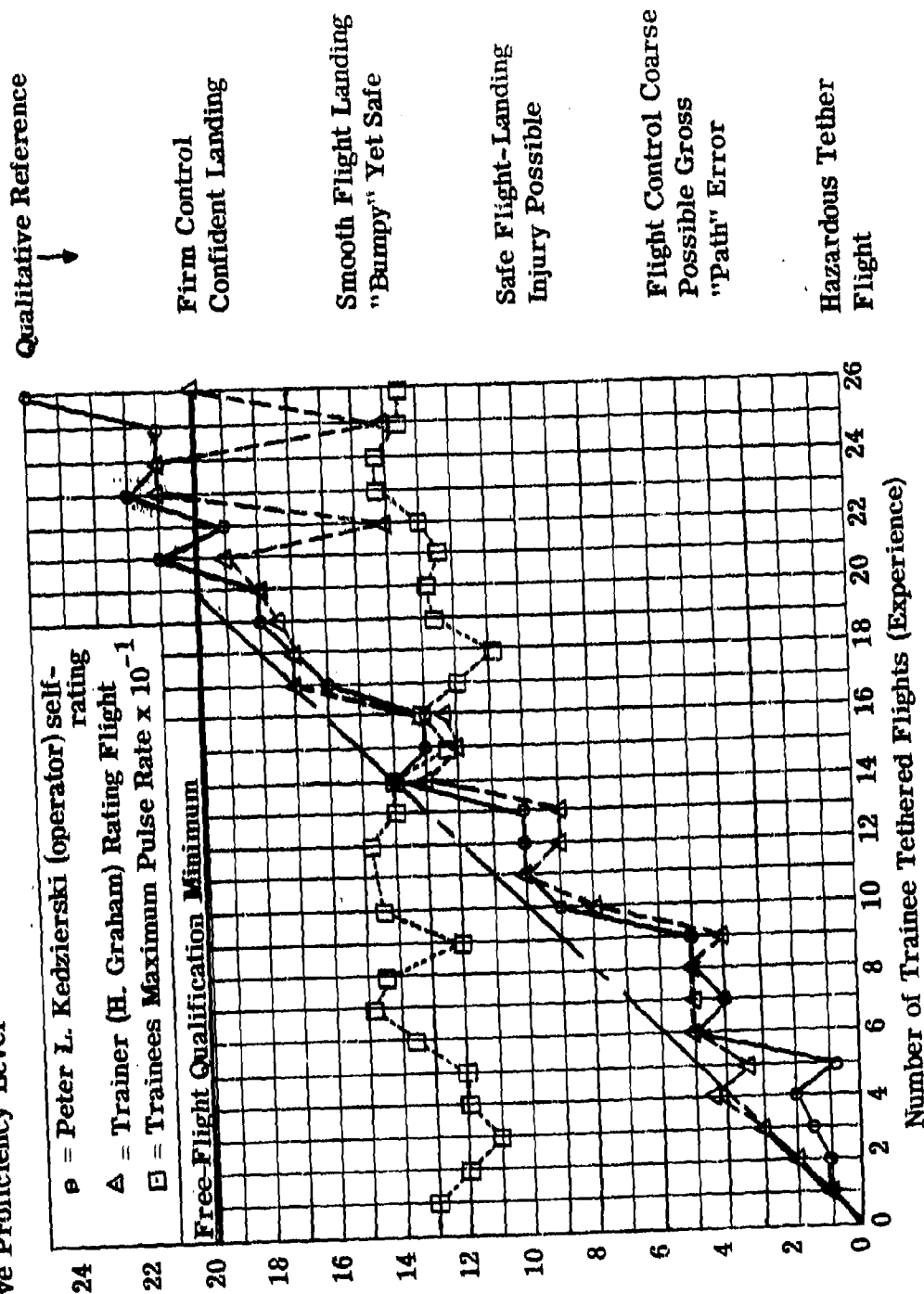


Figure 58. Trainee Proficiency Versus Experience

From general observations, it has been noted that SRLD flight operators tend to have difficulty on the initial attempt, incurring erratic oscillations, and they have to set down due to nozzles being improperly oriented, etc. On the subsequent attempt they tend to be more successful. Figure 59 presents a plot of stop-watch measurements for the trainee's first and second attempt. Note that the time on the second attempt is suggested to be less divergent or more consistent than that of the first; this tends to bear out the general observations that an effective preparatory motor set is important, which is apparently established from cues of the first attempt. Somewhat analogous may be the "tuning" of a musical instrument before playing a melody, or the conventional "warm up" increment in athletic activities.

The difficulty may also be due to a dearth of visual and proprioceptive cues as provided in the present SRLD configuration. In any case, "preparatory motor set" is suggested to be one of the important or problematic training areas.

4. Effect of Inter-trial Interval on Learning

Although no specific plans were made to evaluate the differences between massed and distributed practice on acquisition, the data available from the training program permitted a crude evaluation of these parameters. In the strict sense, we are not dealing with a massed versus distributed situation, since we do not have a series of massed trials that can be compared with a series of distributed trials. We do have, however, a sample of observations in which the inter-trial intervals were approximately 72 hours in duration (i.e., Monday versus Friday trials) and another series of trials in which these intervals were 3 or 4 hours in duration (i.e., afternoon versus morning trials). The former can be regarded as approximating a distributive condition; the latter, a massed condition.

In this fashion, from four to six measures were available for massed practice effects (certain data were missing for some of the variables studied), and four measures were available for distributed effects on the following five indicants of proficiency: total thrust duration; number of attempts on throttles; average duration of each attempt; instructor's flight rating; and, trainee's flight rating. Among the limitations that must be considered in applying the results of this evaluation are:

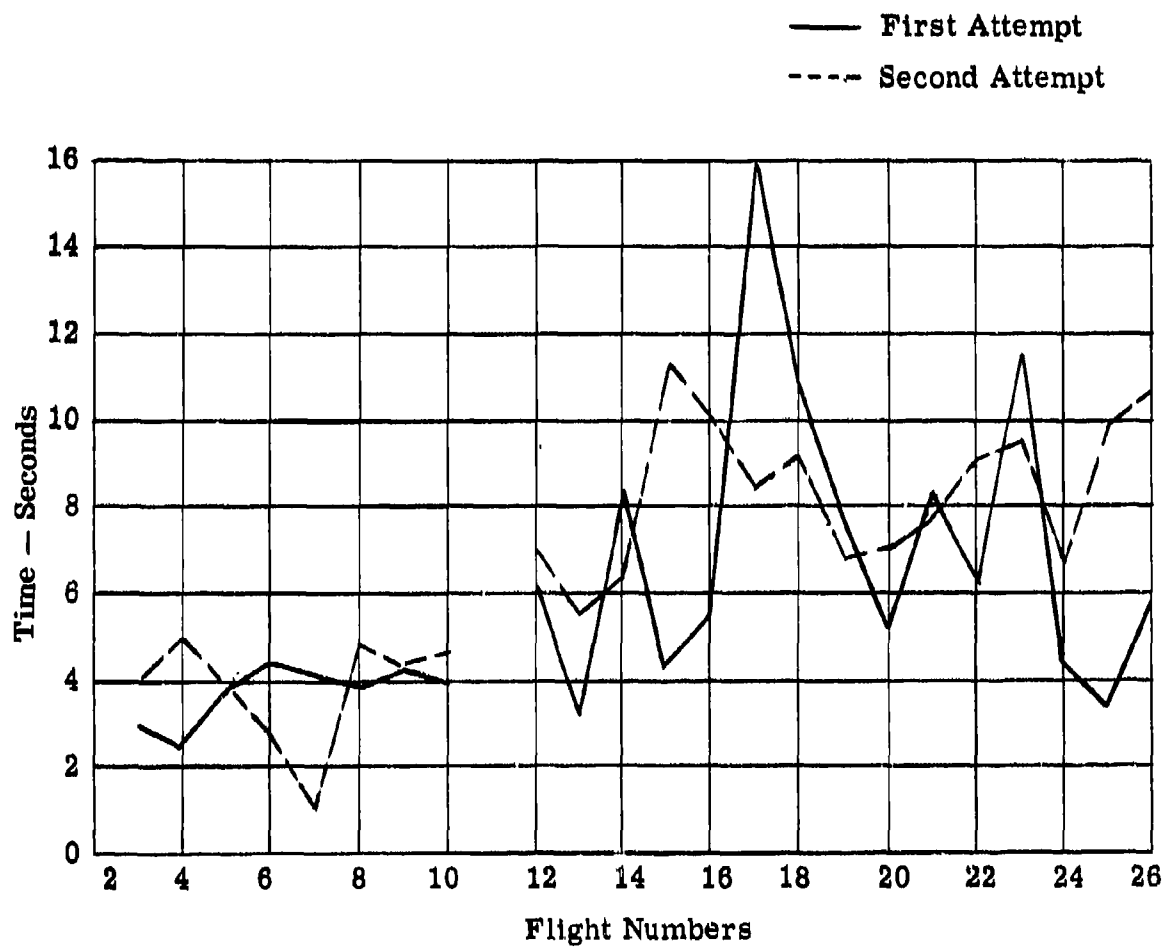


Figure 59. Comparison of Performance on the First and Second Attempts

- a. The distributed inter-trial interval always fell on a weekend; thus, any effects attributed to it may be a function of the activity typically engaged in during the weekend period rather than of time per se.
- b. Massed practice was always based on the comparison of an afternoon trial with a morning trial and may, as a consequence, be confounded with the trainee's diurnal physiological and behavioral patterns.

Howland (Reference 5) remarks: "The majority of studies of motor learning have . . . shown distributed practice to be superior to massed." Accordingly, the hypothesis tested in the current analysis was that performance would show more improvement after the 72-hour interval (distributed condition) than after the 4-hour interval (massed condition).

Table 5 shows the difference in the mean measures for each of the above variables. In each case, the earlier measure was subtracted from the latter, and all positive values indicate that improvement was realized between the first and second measure. Specifically, in the massed condition, morning performance was subtracted from afternoon performance, and in the distributed, Friday performance from Monday, in such a fashion that a positive sign would indicate improvement and a negative, failure to improve.

TABLE 5
COMPARISONS BETWEEN MEAN IMPROVEMENT REALIZED AFTER
LONG INTER-TRIAL INTERVALS (DISTRIBUTED PRACTICE)
WITH MEAN IMPROVEMENT REALIZED AFTER SHORT
INTER-TRIAL INTERVALS

(N = number of observations upon which a given mean is based)*

<u>Performance Index</u>	<u>Mean Improvement</u>			
	<u>Distributed</u>	<u>N</u>	<u>Massed</u>	<u>N</u>
Attempts on Throttle	+1.50	4	-0.60	5
Thrust Duration	+1.65	4	+0.43	4
Mean Duration of Each Attempt	+0.98	4	-0.25	4
Instructor's Rating	+4.25	4	-1.17	6
Flight Rating	+2.38	4	+0.54	6

* (+) plus signs indicate improvement in performance.
 (-) minus signs indicate regression in performance.

There is a striking consistency in the table, showing a greater gain in performance for the distributed condition on all the parameters measured. A Mann-Whitney $\frac{U}{A}$ test (one-tailed) applied to the data yielded the following probability values for the differences between massed and distributed practice:

1. Attempts on throttle	p	0.008
2. Thrust duration	p	0.10
3. Mean duration of each attempt	p	0.029
4. Instructor's ratings	p	0.005
5. Trainee's ratings	p	0.086

All differences were found to be significant at 0.10 level of confidence or better, suggesting that a real difference between the conditions (favoring distributed practice) exists.

The practical significance of this finding (pending support of a more rigorous investigation) is that where time is not of the essence, it may be possible to train operators in fewer flights if the inter-trial interval is sufficiently large. It would thus permit a trade-off of time for dollars. A further consequence of this finding is that the spacing of trials in the proposed training plan should reflect the time-versus-dollars concern of the training agency.

C. SELECTION AND TRAINING CRITERIA

Through a series of individual interviews with the five persons most intimately associated with the SRLD since its development, the following set of selection criteria was developed. The interviewee was asked to describe both the ideal and the minimally acceptable trainee. Interviewees were specifically requested to comment on the following factors: age, height, weight, build, experience, temperament, education, motivation, and motor skills.

According to the consensus, the ideal trainee would possess the following characteristics:

- Age: From 18 to 25 (one respondent increased the upper limit to 30).
- Height: Approximately 5 feet 10 inches (one respondent would accept any height capable of fitting the belt).
- Weight: 150 - 165 pounds (one respondent increased the upper limit to 175).
- Body Build: Slender to medium.
- Experience: Background in aviation or some experience in stressful situations. Work in tasks that call for a high degree of coordination and well developed motor skills. Activity that requires estimation of, and work experience at, altitudes (e.g., paratroopers or high-level construction work). (Most respondents relaxed requirements for this factor due to the low age levels that they specified.)
- Temperament: There was universal agreement in demanding a "cool, calm, nonanxious" temperament. Other qualities specified were: "willingness to take chances" (but not rashly); "quick" and "adventurous" but "not nervous."
- Education: High school graduate to one year of college (this range also reflects the desired youthfulness of the ideal pilot).
- Motivation: Volunteer with high desire to fly the belt (there was universal agreement on this requirement).
- Motor Skills: Most respondents preferred a candidate with a well developed set of motor skills. Special emphasis was given to participation in sports that develop coordination,

sense of balance and equilibrium, timing, quick reaction time, and strong leg muscles.

Minimal qualifications to fly the belt took the following form:

<u>Age:</u>	18 - 45
<u>Height:</u>	Limitations of the belt (one respondent specified from 5 feet, 8 inches to 6 feet).
<u>Weight:</u>	150 to 200 pounds (two respondents would accept any candidate capable of fitting the belt).
<u>Body Build:</u>	Slender to heavy set.
<u>Experience:</u>	All respondents agreed in waiving experience requirements.
<u>Temperament:</u>	Stable with "willingness to take chances" (i.e., ability to function in a potentially hazardous situation).
<u>Education:</u>	At least two years of high school.
<u>Motivation:</u>	Volunteer with desire to fly belt.
<u>Motor Skills:</u>	Some athletic participation (nonsedentary type).
<u>Physical Qualifications:</u>	<p>Respondents differed very little in the physical qualifications specified for the ideal and minimal man, and so for convenience they are combined here. In general, an individual capable of passing the army induction physical was deemed acceptable. One respondent felt that the physical requirements for a commercial pilot's license would be a more suitable criterion for both the minimal and ideal trainee.</p> <p>A more detailed specification of physical requirements by the physician associated with the program included: slim build; no anatomical defects in the extremities; no back defects; neurologically normal; even psyche; pulse and blood pressure within normal ranges; and vision and hearing free from defects and within normal ranges.</p>

Anthropometric Data of SRLD Pilots

To date, four men have flown the SRLD twenty or more times. They ranged in age from 19 to 42 years. Height varied little among them: three were 70.5 inches tall and the fourth 69.5 inches. Weight differences covered a span of 15.5 pounds, with extreme measures of 147.5 and 163 pounds.

In addition, two other men have made one tethered flight on the Bell "B" Belt and successfully achieved airborne status. The first was 42 years old, 69.0 inches tall, and weighed 220 pounds; the second was 35 years old, 71.5 inches tall, and weighed 180 pounds.

The belt has thus successfully accommodated weights ranging from 147.5 to 220 pounds and heights ranging from 69.0 to 71.5 inches. It has, in addition, been handled with reasonable success by an age group that extends from 19 to 42 years of age. These data demonstrate that a fair measure of success has been realized in developing a flexible and controllable design. Table 6 is measured anthropometric data from the four men who have flown the SRLD twenty or more times.

D. TETHERED AND FREE-FLIGHT TRAINING PROGRAM

The plan described below represents the results of efforts generated by Bell R&D funds and an Air Force sponsored contract as well as by funds provided by modification 12 of US Army Contract DA 44-177-TC-642. Within the plan, three major areas are described: orientation, tethered-flight, and free-flight programs. Progression from one training stage to another is based on a simple-to-complex sequence. It is felt that this sequence will serve to develop trainee confidence at an early stage of training and may also serve to facilitate the learning process through the positive transfer of skills acquired on the simple tasks to subsequent, more complex tasks.

Provision has been made for sufficient flexibility to accommodate individual differences in learning in that the number of trials allocated for the mastery of a given subtask may be expanded or contracted to meet the needs of each trainee.

Utilization of dynamic and static training simulators is made both in the orientation and in the flight training program. In this manner they are employed in the familiarization, acquisition and corrective phases of the learning process. With further sophistication in simulation techniques, further savings in training time and efficiency may be anticipated.

TABLE 6.
ANTHROPOMETRIC DATA

	W. F. Moore (8-22-60)		H. Graham (6-28-61)		R. Courter (12-3-62)		P. Kotzierski (12-3-62)	
	Measurement	Percentile*	Measurement	Percentile*	Measurement	Percentile*	Measurement	Percentile*
1. Age	42 yr		27 yr		37 yr		19 yr	
2. Weight	147.5 lb	24	160 lb	50	173 lb	70	154 lb	35
3. Stature	69.5 in.	57	70.5 in.	73	69.9 in.	56	70.5 in.	73
4. Cervical height	59.5	57	64	98	62	90	60.5	74
5. Shoulder height	58.2	77	59	87	58.8	84	58.3	79
6. Suprasternal height	56.5	53	57.2	66	58.5	84	57.8	76
7. Waist height	43.5	80	44.5	91	46	98	42.5	60
8. Crotch height	32.5	43	33	55	35	89	33	55
9. Sitting height	35	25	37	80	34	7	37	80
10. Leg length (Buttock)	41.8	33	43.5	65	46.6	97	42.2	40
11. Arm span	69.5	33	71	53	72.5	73	68	17
12. Arm reach, max from wall	33.5	25	37.5	29	40.5	85	37	19
13. Elbow to elbow breadth	17	45	20	96	20	96	17.5	56
14. Hip breadth	13.3	55	13	40	15	88	13	40
15. Shoulder breadth	18	55	18.5	75	19	88	18	55
16. Chest breadth	11.5	25	11.6	30	13.5	95	12.3	65
17. Waist breadth	10.5	45	11.1	70	12.5	96	12	92
18. Chest depth	9.7	80	8.5	22	10.5	96	7.4	1
19. Waist depth	9.7	96	7.2	20	8.5	75	7	13
20. Neck circumference	14.8	40	15.2	65	15	55	14.3	18
21. Shoulder circumference	45.5	23	42.7	14	45.8	61	41.8	7
22. Chest circumference	36.3	15	36.5	17	40	70	34.3	2
23. Waist circumference	32.5	60	33.2	68	33.3	69	29.9	26
24. Vertical trunk circumference	62	16	63	27	61.5	14	60.8	8

*Anthropometry of Flying Personnel - 1950 WADC TR 52-321

Orientation

Prior to actual flight experience, the trainee will complete the following program of activities:

- Day 1 - AM - A complete medical examination will be given by the Bell Aerosystems Medical Staff to ensure that the trainee's physical condition is acceptable. In addition, the trainee will be issued the following flight equipment: neoprene flying suit, boots, and ear plugs. Observation of the SRLD in actual flight will conclude the morning activities. This flight will be made by the instructor. From a training viewpoint, the flight will serve to familiarize and accustom the trainee to the noise and blast effects of the SRLD.
- Day 1 - PM - Afternoon activities will include an examination of the SRLD with an explanation by the instructor of operational procedures, control functions and the operation of the propulsion system. Flight and propellant hazards will also be discussed. Movies of past flights with comments by the instructor and an opportunity for trainee questions will conclude the day's activities.
- Day 2 - AM - A 1-hour practice session in the use of the yaw and throttle controls will be given on the analog simulator under instructor supervision. This simulator consists of a SRLD-like harness and controls coupled with an oscilloscope display. Blip movements on the scope are controlled by yaw and throttle inputs from the controls. Throttle activation is represented on the scope by vertical deflections of the blip, while horizontal deviations

correspond to yaw inputs. Control blip deflection ratios have been selected to correspond to SRLD characteristics. Discussion of and comment on problem areas will follow the session. Observation of a second SRLD flight and review of the flight with the instructor will conclude the morning activities. This flight will serve to further familiarize and accustom the trainee to the noise and blast effects generated by the SRLD.

- Day 2 - PM - Another practice session on the REAC simulator will be given. This session will be followed by a review of problems encountered and the recommendation of corrective techniques. In addition, the trainee will don the SRLD and be lifted by the tether to achieve familiarization with the lifting sensations produced by the device.
- Day 3 - AM - Further REAC training and observation of a third flight followed by yaw control training on the air bearing platform will constitute the morning activities. The flight will serve to further promote trainee familiarization and adaptation to the SRLD. Experience with the air bearing platform will serve to develop proficiency in the use of a left-hand twisting movement for yaw control in a situation where actual changes in body orientation are produced as a function of control inputs. In this situation, the trainee is seated on a stool mounted on an air bearing platform with a control stick at his left hand. By twisting the control stick in the direction of desired movement, the operator induces corresponding change in orientation of the platform.
- Day 3 - PM - Afternoon training will consist of additional REAC practice with yaw and throttle controls. Additional experience in the lifting effects of the apparatus will also be given. The afternoon program will conclude with a review by the instructor of the control problems and hazards peculiar to the SRLD. An opportunity for the trainee to raise questions about any problems that remain will also be afforded. Finally, an evaluation will be made of the trainee's readiness for flight training.

Day 4 - AM - Tethered flight experience will begin for the trainee if evaluation indicates he has attained the appropriate degree of readiness. This flight will be followed by an instructor-trainee review of the problems encountered; in addition, methods of correction will be discussed.

Day 4 - PM - Trainee will be assigned analog simulator practice aimed at removing major deficiencies noted in the morning flight.

Remaining Schedule

Flights will continue at a one-a-day pace until evaluation indicates that the trainee is capable of undergoing a more rigorous schedule of two or more flights a day. It is anticipated that a two or three flight per day schedule may be reached by the second or third week of training and continued until the forty flight series is completed.

Flight Plan

The flight plan for this study was developed with the major goal of training a naive subject to maximum proficiency in a minimal amount of time. Since safety considerations demand tethering during initial training, while the development of adequate skill in handling the control and stability characteristics of the man-machine system requires the elimination of extraneous constraints, two flight sequences will be used to achieve the above objective: a tethered sequence to develop the ability to achieve and maintain safe airborne status and a free flight sequence to develop proficiency in the performance of a variety of maneuvers.

Tethered Flight Sequence

To achieve the first goal, the training schedule was designed to proceed from mastery of the easiest control tasks to mastery of the more complex. This procedure was based on the recommendations that grew out of the development studies: the considerations that such an approach would work to instill maximum confidence in the trainee, and would also capitalize on any transfer effects that might occur in a manner that would reduce the learning time required to master the more difficult tasks.

It is to be noted, however, that simple adherence to such a plan is neither possible nor desirable. In the first place, the characteristics of the SRLD are such that certain control tasks, regardless of their difficulty, must be mastered at the outset if the system is to become airborne. For example, although thrust control was relatively difficult to master, adequate manipulation of this component must be achieved at the outset since it is essential in attaining airborne status. Secondly, the data on which the degree of difficulty of a given control operation is based are drawn from the subjective opinions of the operator and observers and might be subject to bias in the sense that what was looked for in a given test might have been a function of past problems encountered. Additionally, the configuration was repeatedly changed and modified during developmental test and, as a consequence, the effect of equipment change was confounded with operator learning.

In analyzing the overall control task, it was felt that it would be profitable to break it down into the following components: control of linear movement along the longitudinal, lateral, and vertical axes, control of angular movement about these axes (pitch, yaw and roll) and thrust control. A frequency distribution of the number of times these components were cited as a problem in the descriptions of flights 6 through 64 of the developmental test operator is given in Table 7. The problems cited consist of both system-induced difficulties (e.g., inadvertent yaw) and performance difficulties (failure to perform a specified mission such as inability to adequately control attitude in executing a semicircular turn).

TABLE 7
FREQUENCY OF PROBLEMS ENCOUNTERED IN SRLD
DEVELOPMENTAL FLIGHTS FOR EACH CONTROL COMPONENT

<u>CONTROL COMPONENT</u>	<u>NUMBER OF TIMES CITED AS A PROBLEM</u>	<u>RANK</u>
1. Throttle control and rate	16	5.5
2. Longitudinal movement	16	5.5
3. Lateral movement	11	4.0
4. Vertical movement	10	3.0
5. Yaw	18	7.0
6. Pitch	7	2.0
7. Roll	1	1.0

In comparing the rank order of difficulty obtained for each control component in the initial flight with the order of introduction of each component in the proposed training series, several deviations occur (Table 8).

TABLE 8

RANK ORDER OF DIFFICULTY OF CONTROL COMPONENT IN DEVELOPMENTAL TESTS COMPARED WITH ORDER OF INTRODUCTION OF COMPONENT IN TRAINING SERIES

CONTROL COMPONENT	RANK ORDER OF DIFFICULTY IN DEVELOPMENT TEST*	ORDER OF INTRODUCTION IN TRAINING SERIES**	(I-II) DIFF.
	(I)	(II)	(I-II)
1. Roll	1.0	3.0	2.0
2. Pitch	2.0	1.5***	0.5
3. Vertical	3.0	7.0	4.0
4. Lateral	4.0	5.0	1.0
5. Longitudinal	5.5	6.0	0.5
6. Throttle	5.5	1.5***	4.0
7. Yaw	7.0	4.0	3.0

* Rank 1 = Easiest

** Rank 1 = First introduced

*** The value 1.5 refers to the fact that pitch and throttle were introduced first simultaneously. The total of rank positions one and two being three, the average value of 1.5 is shown.

If the table is redrawn so as to ignore the components that must be considered first because of system constraints (throttle and pitch control), the only deviations that remain between the training order and level of difficulty are yaw and vertical control. These deviations are a function of including yaw control much earlier and vertical control much later in the training series than warranted by the level of difficulty noted in the developmental trials. This reversal was made because it appeared reasonable to develop maximum control of angular movement about the axes before perfection of linear movements was undertaken; and although vertical control ranked only third in order of difficulty, this problem was still prevalent at the end of the initial flight tests and appeared to be the parameter that was studied with only minimal concern.

With the above considerations in mind, the following tentative flight plan was developed for the tethered series (Table 9). Excluding the first two trials, where two control tasks are introduced simultaneously due to

the demands of the system, each control task is introduced individually. A number of trials are allowed in which the trainee's attention is focused on the mastery of a particular task and all other tasks are given secondary concern. As soon as a given task is mastered, additional trials are allowed for the integration of this task with the others that have been previously mastered. The plan proceeds in this fashion until all of the tasks have been learned and integrated.

Although the training program emphasizes the development of skill in one control task at a time, it must be recognized that this emphasis is relative rather than absolute. Of necessity, the operator is faced with the task of maintaining minimal standards of stability on all control tasks in order to achieve airborne status. As a consequence, the basic training task will be a series of short horizontal translations in which the operator will attempt to develop proficiency in one or two control tasks, while paying only a minimal amount of attention to the other tasks which are necessary to remain airborne. For example, during the initial trials, the operator will attempt to perfect his control of thrust and pitch without concerning himself with achieving perfection in maintaining longitudinal, lateral, vertical, yaw, or roll control. This is not to say that these other tasks will be completely ignored, but rather that they will be given attention only 'insofar' as they interfere with the primary objective of perfecting thrust and pitch control.

It is to be further recognized that the proposed training schedule presented in Table 9 will be modified as the performance of the trainee warrants; more or fewer trials on a given task will be assigned as proficiency is evidenced in his performance.

Establishment of Free-Flight Readiness:

Determination of trainee readiness for free flight will be made at the observational level of analysis. Basically, the assessment of free-flight readiness will rest on the following criteria:

1. Trainee expression of confidence that he is prepared for free flight.
2. Demonstrated flight proficiency on three consecutive tethered flights. These flights should display that the trainee has attained sufficient mastery of the control device to avoid potentially

TABLE 9
FLIGHT PLAN FOR TETHERED SEQUENCE
CONTROL TASK

Trial	Longitudinal	Lateral	Vertical	Yaw	Pitch	Roll	Throttle	Flight Mission	Phase of Flight Emphasized	Items of Concern re Position in X, Y, and Z Axes
	X	Y	Z	ψ	θ	ϕ				
1					1		1	Short Hops	Take-off and Landing	Characteristics of movement in X, Y, and Z Axes of no concern.
2					1		1	Short Hops		
3					2	1	2	Short Hops		
4				1	3	2	3	Short Hops		
5				1	3	2	3	Short Hops		
6										
7				1	1	1	1	Translations	In-flight performance	No distance or altitude specified.
8		1		2	3	3	3	Translations	Take-off and landing as well as in-flight performance.	Lateral deviation to be minimized.
9		1		1	2	2	1	Translations		
10		1		1	1	1	1	Translations		
11	1									
12	1	2		3	3	3	3	Translations	In-flight performance	Distance specified but not altitude.
13	1	1		2	3	2	2	Translations	Take-off and landing as well as in-flight performance.	Lateral deviation to be minimized.
14	1	1		1	2	1	1	Translations		
15	1	1		1	1	1	1	Translations		
16	3	2	1	3	3	3	3	Translations	In-flight performance	Distance and altitude specified.
17	2	2	1	3	3	3	3	Translations	Take-off and landing as well as in-flight performance.	Lateral deviation to be minimized.
18	1	2	1	2	2	2	2	Translations		
19	1	1	1	1	1	1	1	Translations		
20	1	1	1	1	1	1	1	Translations		

EXPLANATION OF PRIORITIES:

- (1) Objective to attain proficiency in this control task; i.e. to attain ability to keep error at 0 point.
- (2) As far as consistent with primary task, error is to be kept at 0 point.
- (3) As far as consistent with (1) and (2) error is to be kept at zero point.

Blank - only concern is to maintain sufficient control to insure airborne status.

hazardous flight conditions and in particular has demonstrated a smooth landing technique free from stumbles and excessive momentum.

3. The concurrence of medical, flight-test, project, and human-factors personnel that the above conditions have been fulfilled.

It was hoped that data acquired in the Air Force program would have highlighted some objective indices that might have been employed in this assessment (e.g., reduction in tethering required or in rms error scores). Unfortunately, instrumentation difficulties encountered in that program precluded the accomplishment of this objective.

Free-Flight Sequence

In this series of flights, the primary concern will be on developing skill in handling the control and stability characteristics of the SRLD-man combination in the execution of different maneuvers. To this end, three maneuvers have been selected, each of which emphasizes a different problem in translation along one of the three axes (lateral, longitudinal, or vertical).

These maneuvers consist of the following missions:

1. Horizontal translation - emphasizing translation along the longitudinal axis.
2. Translation over a barrier - emphasizing vertical control.
3. Slalom - emphasizing lateral control.




It is to be noted that the above maneuvers represent those that were most readily performed in the developmental free-flight series and are listed in the sequence of easiest to most difficult.

A given maneuver (starting with the easiest) is to be performed until asymptotic performance appears to have been reached before the next maneuver is attempted. Table 10 contains a diagrammatic description of each maneuver.

E. TRAINING OF MAINTENANCE AND SERVICING PERSONNEL

At this stage of development, the following selection criteria and training program appear desirable for maintenance and servicing personnel.

TABLE 10
FREE-FLIGHT PLAN

- | | | | |
|----|--|--|--|
| 1. |  <p style="text-align: center;"><u>Top View</u></p> | <u>horizontal translation</u> | |
| | <u>Number of trials:</u> | Mission performed until evidence that an asymptote has been reached. | |
| | <u>Purpose:</u> | To develop control and stability proficiency in straight, horizontal flight. | |
| | <u>Emphasis:</u> | On longitudinal control. | |
| 2. |  <p style="text-align: center;"><u>Barrier</u>
<u>Side View</u></p> | <u>translation over barrier</u> | |
| | <u>Number of trials:</u> | Same as No. 1. | |
| | <u>Purpose:</u> | To develop control and stability proficiency relative to altitude control. | |
| | <u>Emphasis:</u> | On vertical control and coupling of pitch and throttle control. | |
| 3. |  <p style="text-align: center;"><u>Top View</u></p> | <u>slalom</u> | |
| | <u>Number of trials:</u> | Same as No. 1. | |
| | <u>Purpose:</u> | To develop control and stability proficiency in horizontal flight coupled with lateral movement. | |
| | <u>Emphasis:</u> | On control of lateral movement, and coupling of yaw and throttle control. | |

The individual selected should have: proven mechanical ability; a demonstrated ability to accept responsibilities and carry them out faithfully and fully; and, sufficient technical background to achieve an adequate understanding of the safety and handling requirements of peroxide propellants.

Training requirements should include lectures, demonstrations and literature dealing with propellant characteristics and management techniques, as well as with the physical and operating characteristics of the SRLD. This background should then be supplemented with on-the-job training experience under the supervision of competent servicing personnel.

V. INDEPENDENT R&D PROGRAM

During the past year, Bell Aerosystems has engaged in an independent research and development study on the SRLD Program. This study consisted of configuration work as well as performance calculations. It had as its objective the design goals of obtaining minimum weight, longer ranges, and lower production costs.

We investigated cleaned-up, pressurized configurations of the SRLD as well as several pump-fed versions and configurations of each utilizing tip-jet-driven fans. Table 11 is a summary of the general characteristics and maximum ranges obtainable from the configurations which we investigated.

TABLE 11
CALCULATED PERFORMANCE OF VARIOUS SRLD CONFIGURATIONS
UTILIZING H_2O_2 AS PROPELLANT

No.	Configuration Studied	SRLD Weight Empty (lb)	Propellant Weight (lb)	Maximum Range (ft)
1.	60-Pound Pump Version - Nozzles	25	35	1180
2.	Bell "B" Belt*	68	47	1200
3.	"V" Belt	55	47	1420
4.	Torus Tank Belt	45	47	1630
5.	Pump Version - Nozzles	34.5	63.5	2370
6.	"V" Belt - Tip Jet Fans	85	47	3300
7.	Pump Version - Nozzles	30	95	4500
8.	"V" Belt - Expander Turbine Fans	85	47	6000
9.	Pump Version - Tip Jet Fans	60	95	10,000
10.	Pump Version - Expander Turbine Fans	60	95	18,000

*Actual Flying Belt in Existence.

Comparing the merits of the above configurations, it becomes obvious that a pumped, unpressurized type of rocket propulsion system shows a great

advantage in range, but only if the tank capacity is greater than about 50 pounds. As the tank capacity is increased, the range goes up sharply. A comparison of this 60-pound gross weight pump version with the lightweight, cleaned-up pressurized version indicated the same general performance. It would stand to reason, therefore, that the pressurized version is generally optimized at about this design point.

A study of the preliminary performance data fundamentally indicates that, in view of the 4500-foot range of the 95-pound propellant, unpressurized pump version, it would be a very desirable design to employ in future models of the rocket belt. It should be pointed out that this version was identical in weight to the original feasibility model. The use of the hip-pack type corset permits the operator to walk around within reasonable distances with the loaded belt without a great amount of fatigue.

Data on the tip-jet fans indicate a two-to three-fold increase in possible SRLD range. For example, if fans were used in conjunction with the 95-pound unpressurized pump version, the possible range could be increased to something over two miles.

A preliminary look at the use of jet engines for flying belts instead of fundamental rocket power indicates the greatest practical range achievement. The empty weight, however, would be considerably greater and more complicated than the rocket-powered versions. This, however, would be more than offset by the jet engine's ability to use kerosene as a fuel and would lead to more widespread tactical use.

As a result of the very significant theoretical increase in range shown possible with the use of tip-jet fans, Bell decided to detail design and fabricate a pair of these fans for actual flight testing on the "B" belt. At this writing, the fans are in process of assembly and will soon be tested.

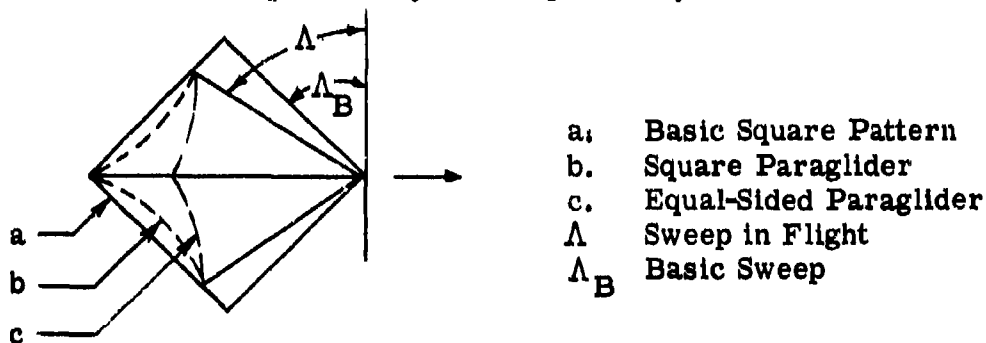
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APPENDIX I
SUPPLEMENTARY INFORMATION

The following paraglider information was received during a visit to Langley Field, Virginia on 9 January 1962.

1. Pitching moments are referred to the keel length (to apex of leading edges). Rolling and yawing moments are referred to the span length. Reference area (s) means "area of flat pattern" or "fabric area".
2. From a towing standpoint, an equal length (no square) paraglider towed good when sweep was fixed at 55 degrees and 60 degrees. For a fixed sweep of 50 degrees, the towing qualities were very bad. This was believed to be the result of too little fabric area near the trailing edge of the wing at the lower sweep angle, which means less directional stability. A square surfaced paraglider of fixed sweep angles of 55 degrees and 60 degrees also had good towing qualities and would possibly have towed good at a sweep of 50 degrees also, because of the increased fabric surface of a square wing leading edge. The latter assumption has yet to be proven by tests

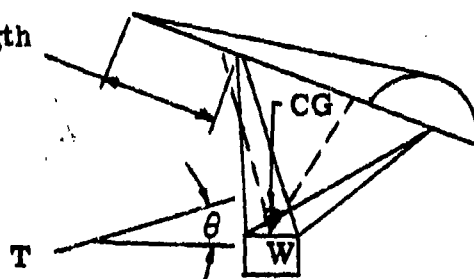


3. Variable-sweep (spring nose) paragliders towed better than fixed-sweep wings. The following towing characteristics were noted:
 - a. If the attachment point was above the optimum towing point, a diving, oscillating motion from side to side occurred.

- b. If the attachment point was below the optimum towing point, the wing towed good at first but finally went into a slow diving-yawing motion to one side only.

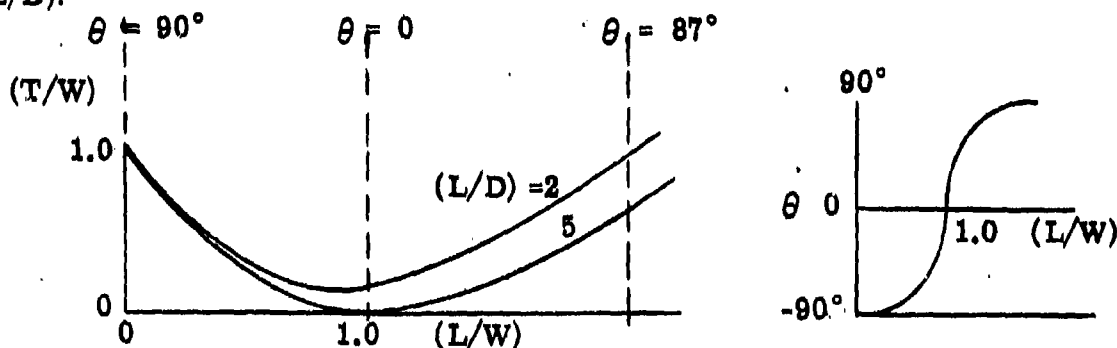
A good towing configuration was found to be as follows:

1/3 Keel
Length



— Keel Shrouds
- - L. E. Shrouds
T Towing Cable Tension
L Lift

The towing angle (θ) was found to be a function of C_L , (W/S) and (L/D).



4. "Bolting" of the trailing edge has a very pronounced effect on (L/D) and the pitching moment. A 3.6 percent "bolting" of the basic 45 degree swept wing at $\Delta = 55$ degrees increased (L/D) by 16 percent at $\alpha = 32.5$ degrees and 33 percent at $\alpha = 42$ degrees. Bolting is the shortening of the trailing edge length by attaching a line to it and applying tension to the line.
5. If the leading edge diameters do not exceed 4 - 5 percent of the leading-edge length, there will be no appreciable adverse effects on the wing L/D .
6. Fabric should be attached so as to be tangent to the outside of the leading edges.

7. Displacement of the leading edges below the keel may reduce the hinge moments.
8. NASA wind-tunnel test data of an equal-sided paraglider with a basic sweep of 45 degrees are as follows:

$\Lambda \sim^\circ$	(L/D)	C_L	$\alpha \sim^\circ$	C_M
50 ↓	5.30	0.47	18.5	0.016
	5.25	0.54	20.5	0.018
	4.95	0.63	23.0	0.022
	4.55	0.73	24.8	0.028
	4.05	0.83	27.0	0.032
	3.45	0.92	29.0	0.038
	2.65	1.07	33.0	0.037
55 ↓	4.70	0.45	20.0	0.005
	4.55	0.58	28.5	0.008
	4.00	0.72	32.5	0.012
	3.05	0.88	37.0	0.022
	2.00	1.06	45.0	0.012
60 ↓	3.95	0.41	28.5	
	3.95	0.53	33.5	
	3.60	0.64	36.5	
	3.05	0.72	40.5	
	2.00	0.89	49.0	

Present
Design

$\Lambda \sim^\circ$	$\alpha \sim^\circ$	$\beta \sim^\circ$	C_ℓ	C_n	C_y
55 ↓	24.5 ↓	-5	0.003	-.0015	0.035
		0	-.001	0	0
		5	-.008	0.0025	-.028
		10	-.012	0.0042	-.060
		15	-.017	0.0055	-.095
↓	41.0 ↓	-5	0.005	0.0015	0.015
		0	-.0025	-.001	-.005
		5	-.010	-.003	-.025
		10	-.016	-.005	-.050
		15	-.023	-.008	-.075

where C_M - pitching moment coefficient
 C_L - rolling moment coefficient
 C_n - yawing moment coefficient
 C_Y - side force coefficient
 β - side slip angle
 α - angle of attack

APPENDIX II

"A" BELT SUPPLEMENTAL TEST DATA

The Phase III program began with installation of the "A" SRLD belt in a test cell to determine propulsion system performance subsequent to the Phase II flight test and demonstration program. It was found to be performing very satisfactorily after 216 runs and about 1-1/2 hours accumulated running time. Consequently, it was put back into service without changing the original catalyst bed or replacement of other components. Specific data are presented under the flight test section of this report.

The following parameters were measured:

1. Gas Generator Pressure (Dual Instrumentation)
2. Propellant Feed Pressure
3. Propellant Tank Pressure
4. Nitrogen Source Pressure
5. Propellant Flow Rate
6. Gas Generator "Combustion" Temperature
7. Propellant Feed Temperature

Three full-duration firings were performed. Two runs were at constant full thrust and one was a thrust variation run. An analysis of these (84 min.) data was made, and compared with like data taken at the 3-minute and 44-minute accumulated firing times:

<u>Catalyst Bed Time</u>	<u>3 min</u>	<u>44 min</u>	<u>84 min</u>	<u>Overall % Change</u>
Thrust (at sea level) - lb	282.8	280.9	282.5	0.0%
Characteristic Velocity (c*) - ft/sec	3010.0	3010.0	3000.0	-0.3%
Specific Impulse (I_{sp}) - sec	121.5	121.5	120.9	-0.4%

Insomuch as the propulsion system had not been checked for H_2O_2 compatibility for a period of five and one-half months, it was done and found to be in excellent condition. Decomposition curves are presented in Figure 80.

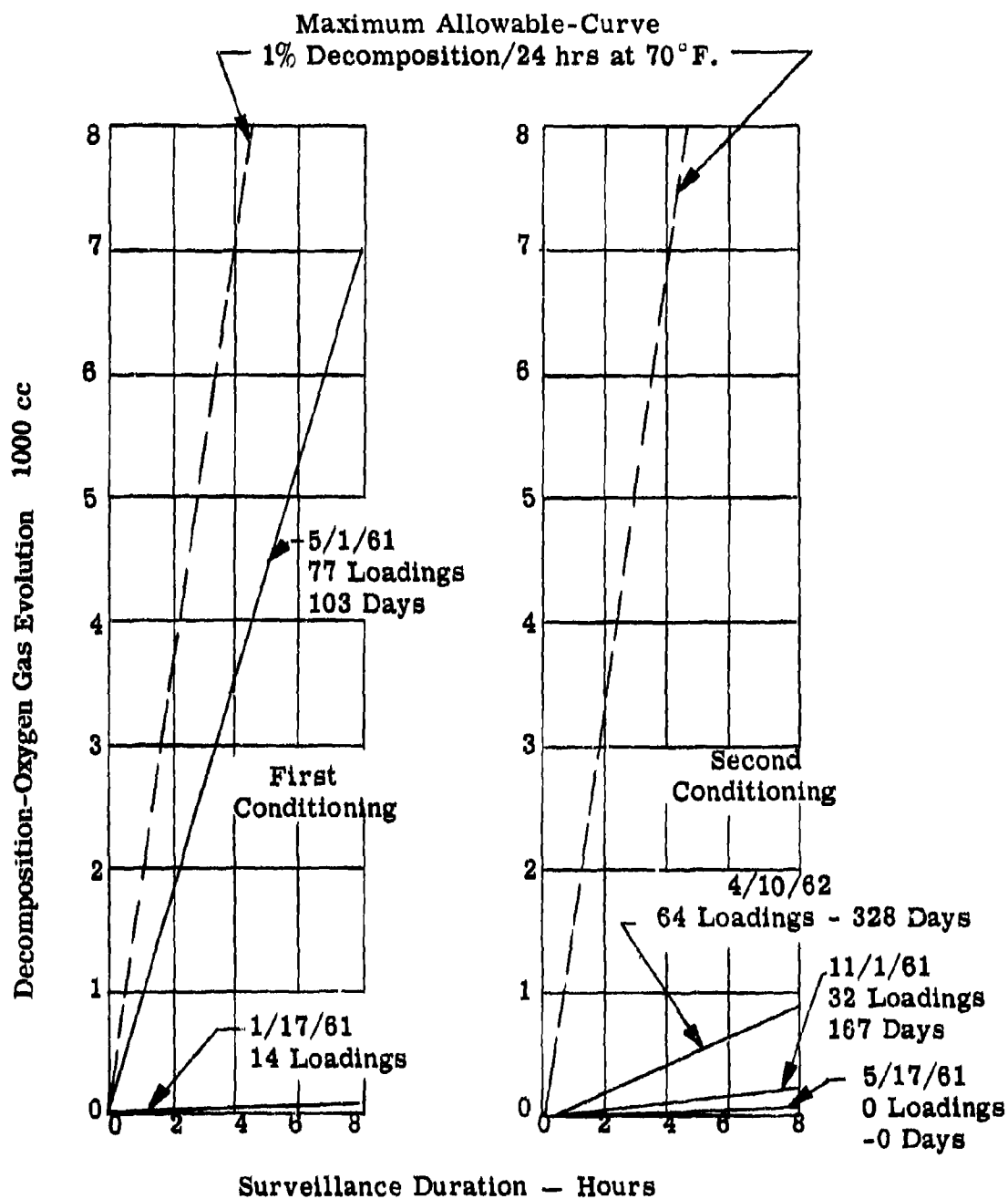


Figure 60. "A" Belt Propellant System (90% H_2O_2) Compatibility as a Function of Tank Loadings and Total Days Since Last Conditioning Process

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Borass, N. Carrierio et al. Report
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pp. (Contract DA 44-177-TC-642),
USATRECOM Task 1D121401A14175.

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